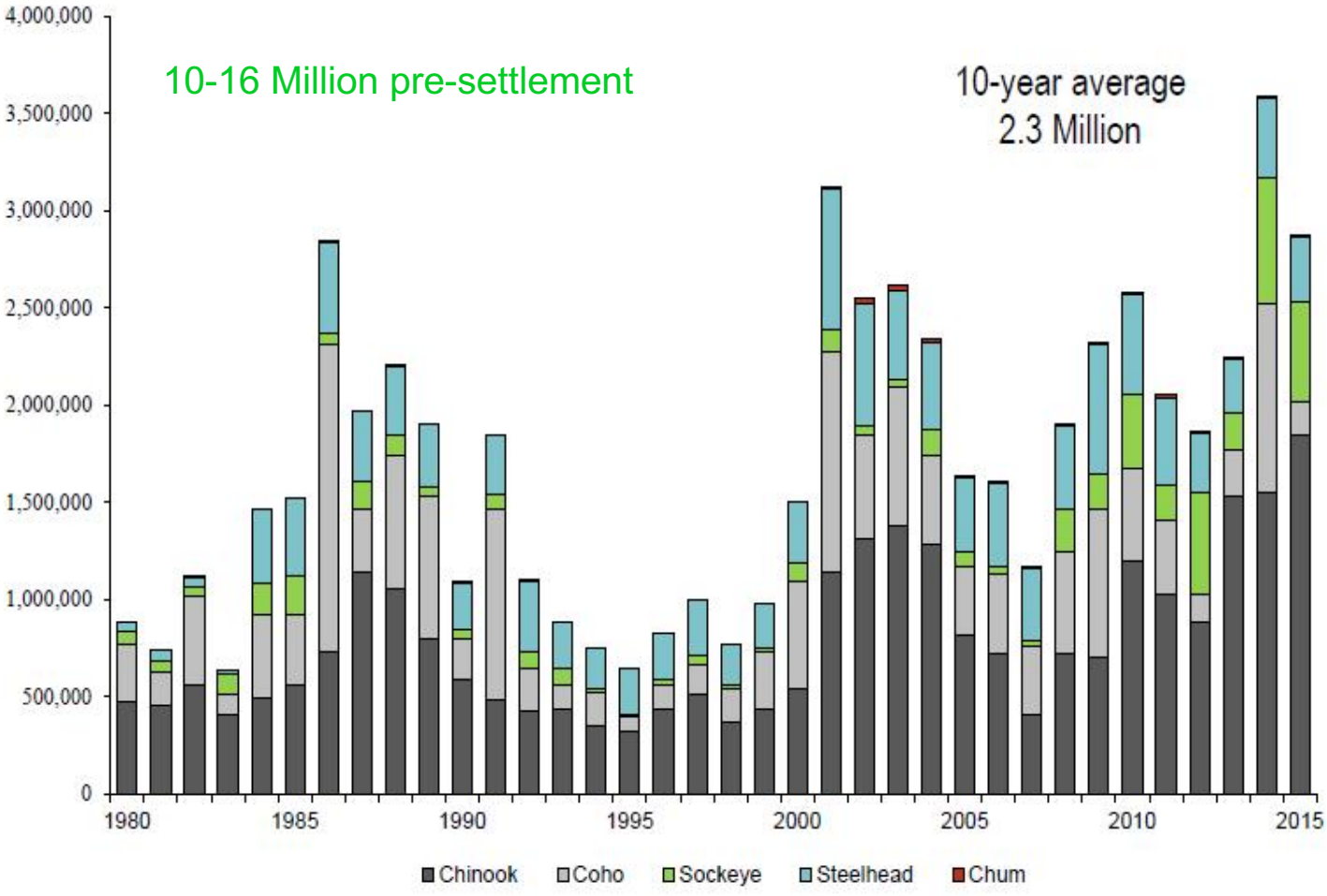
Lower Columbia River Cold Water Refuges & How Fish Use Them

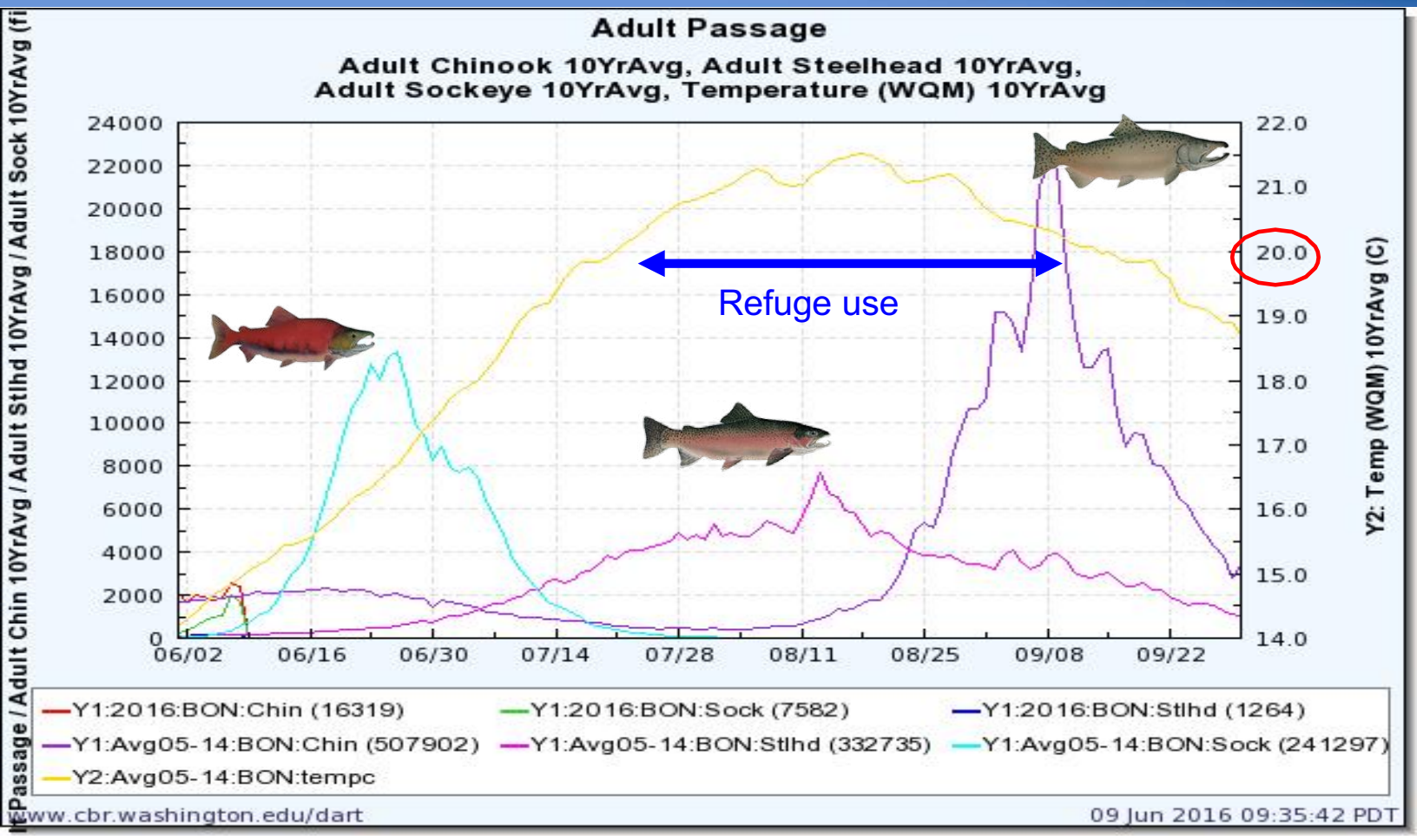
Public Workshop
November 2017

John Palmer
EPA Region 10

Columbia River Salmonid Returns



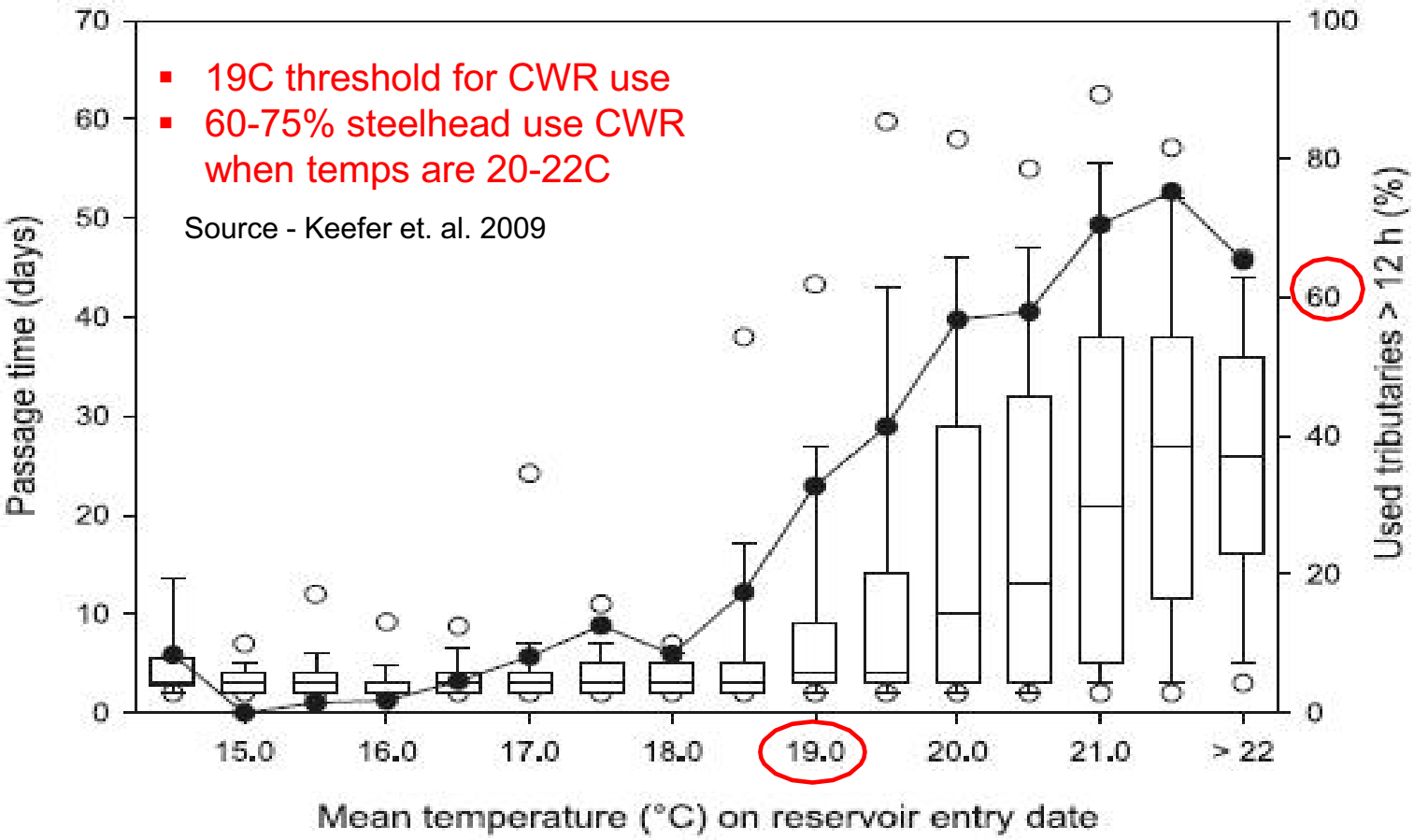
Bonneville Dam Temperatures and Fish Passage



Steelhead use of CWR

- 19C threshold for CWR use
- 60-75% steelhead use CWR when temps are 20-22C

Source - Keefer et. al. 2009



Chinook use of CWR

- 21C threshold for CWR use
- 20-40% use CWR with 21-22C
- Underestimate - plume use not fully counted

Source - Goniea et. al. 2006

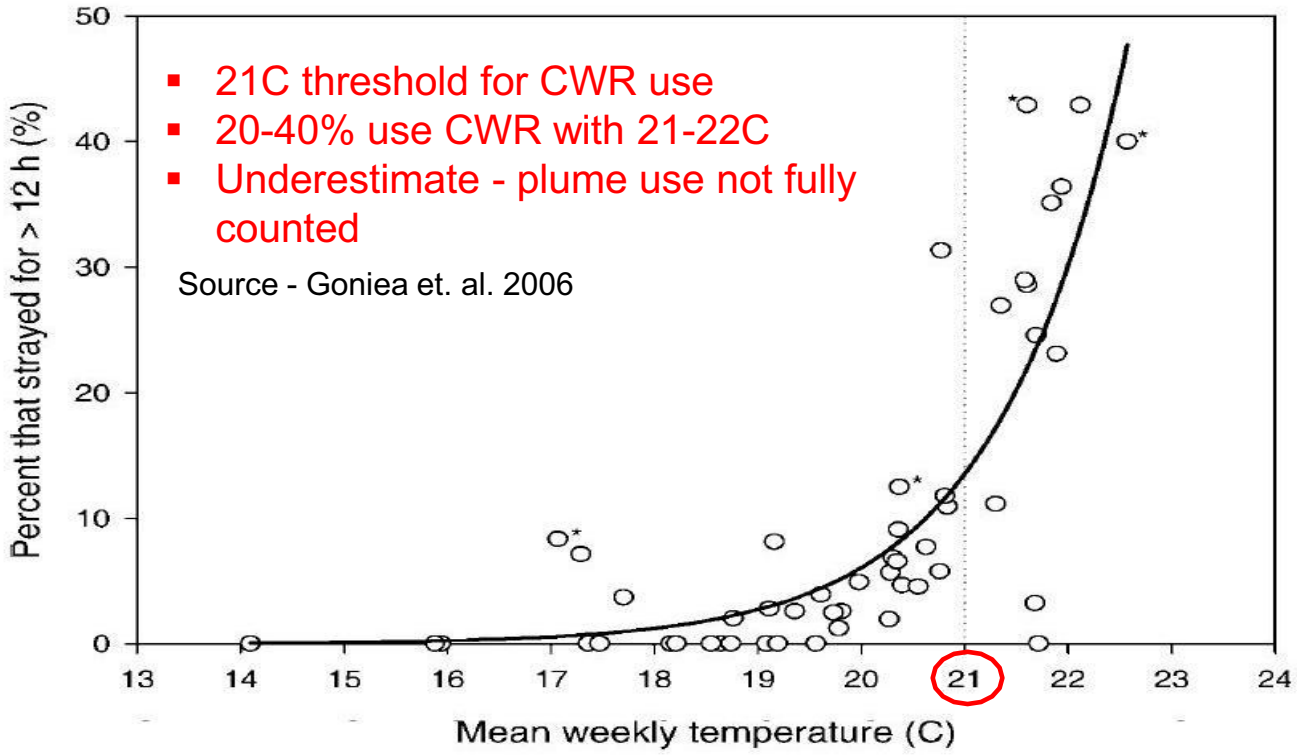
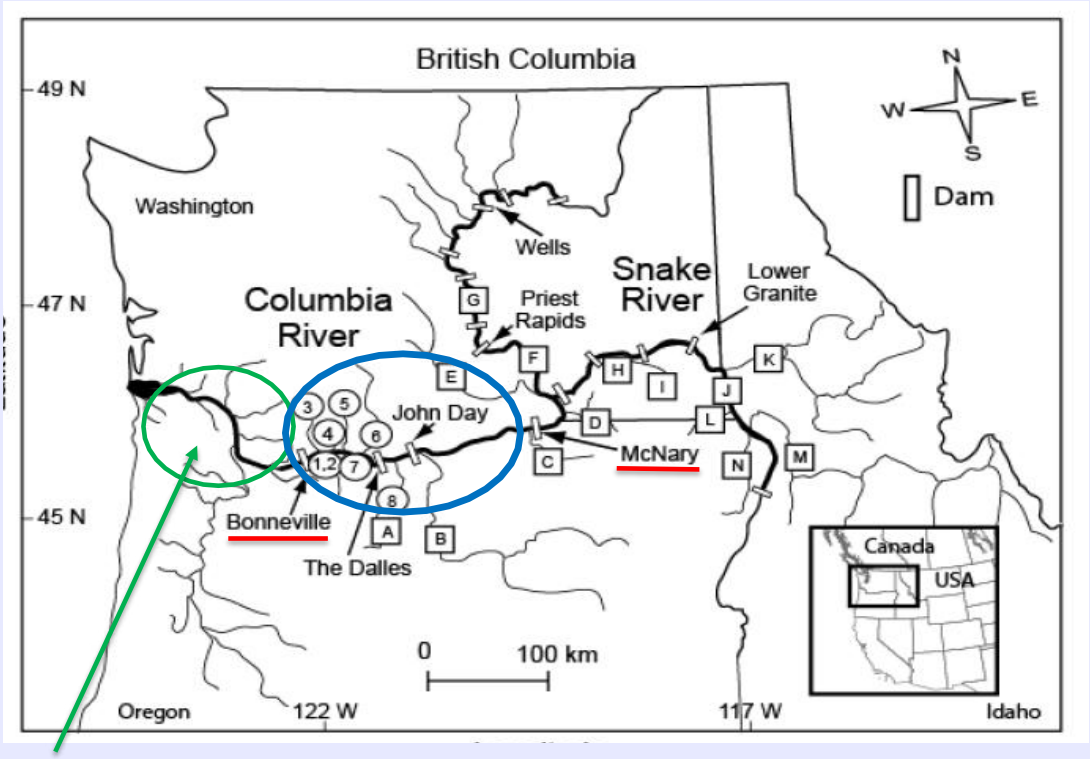


FIGURE 6.—Relationship between the percent of fall Chinook salmon that used (>12 h) coolwater tributaries and mean weekly water temperatures at Bonneville Dam. Circles represent 52 weekly bins (mean = 41 fish/bin; range = 4–122 fish/bin). The curve is the exponential regression line that best fits the data ($r^2 = 0.80$; $P < 0.0001$; percent $= 6.558^{-7} e^{0.802 \times \text{temperature}}$). Asterisks indicate data points with fewer than 10 fish.

Eight Primary CWR Areas studied in Columbia River from Bonneville Dam to McNary Dam

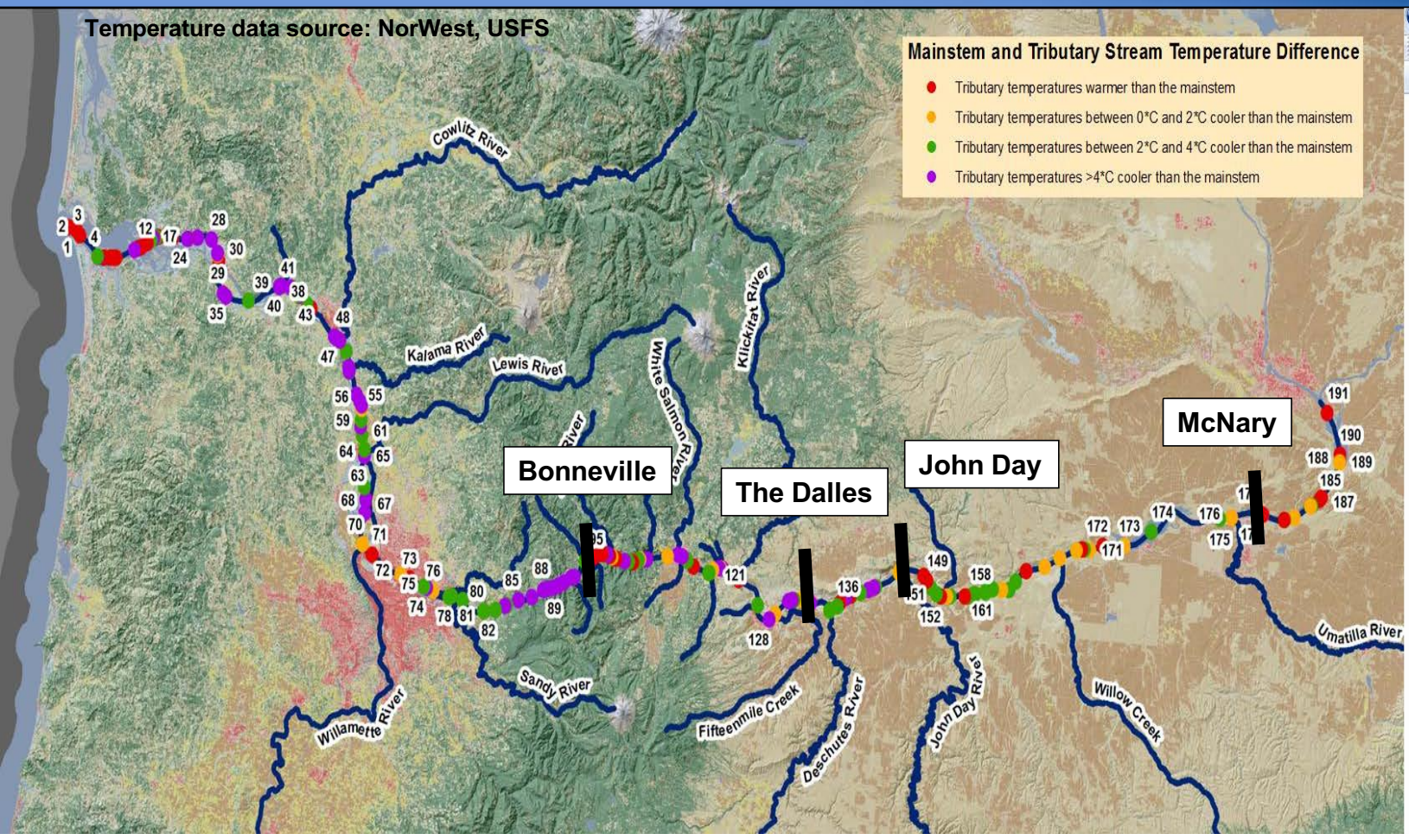


1. Eagle Creek
2. Herman Creek
3. Wind River
4. Little White Salmon River
5. White Salmon River
6. Klickitat River
7. Hood River
8. Deschutes River

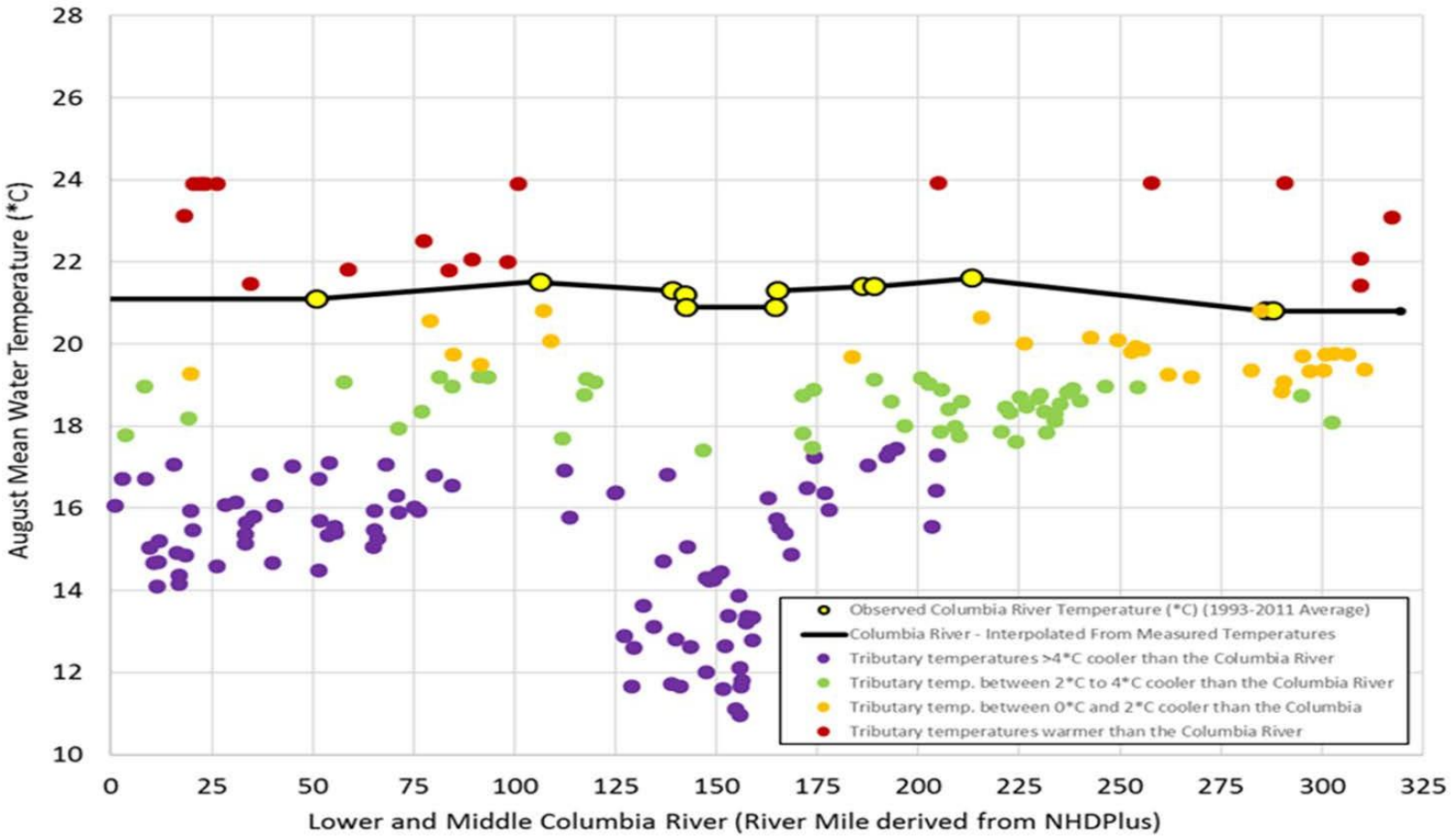
Little CWR research below Bonneville Dam

Source - Keefer et. al. 2011

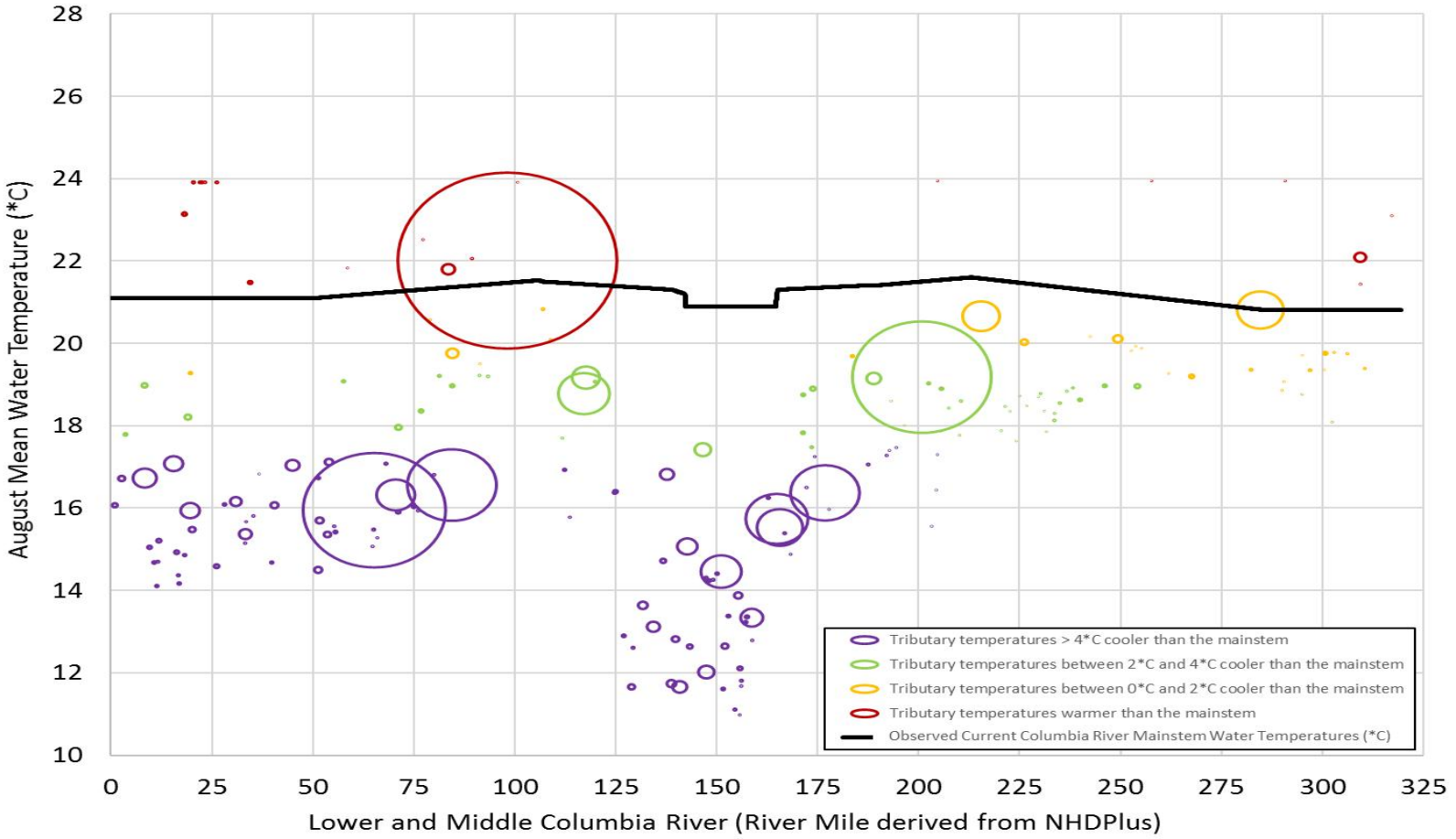
191 Columbia River Tributaries below Snake River Confluence



August Mean Tributary Temperature



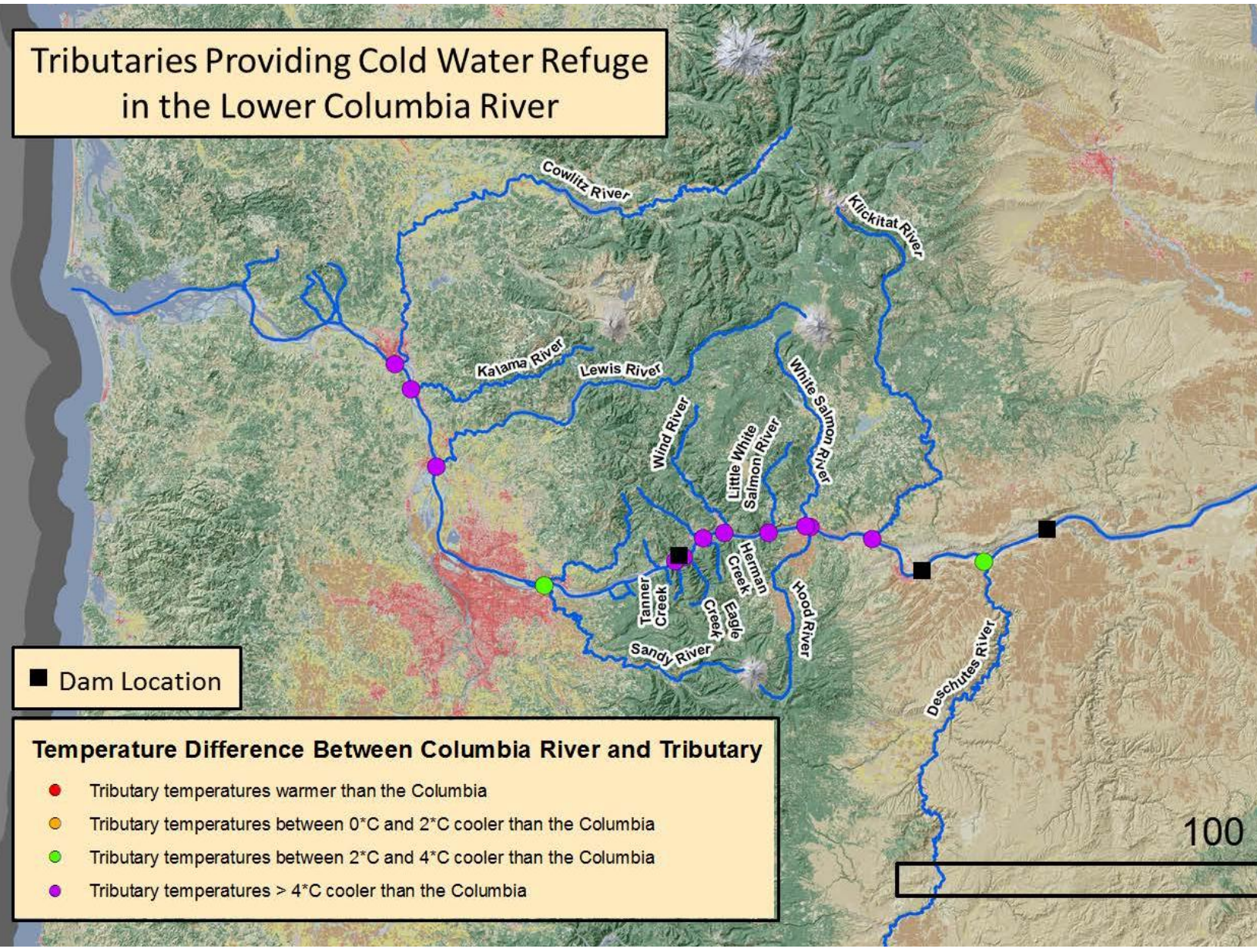
August Mean Temp w/Flow Representation



Screening Criteria to Identify CWR Tributaries

1. August mean temperatures at least 2°C cooler than Columbia River and August mean flow greater than 10 cfs
2. Added small cold tributaries (August mean of 16°C or cooler and August mean flow 7-10 cfs)
3. Added larger rivers (Aug. mean flow 10 cfs or greater) that have periods of time at least 2°C cooler than Columbia River
4. Removed tributaries that have limited or no access to the cold water plume

Note: Also evaluated other CWR potential


Tributaries Providing Cold Water Refuge in the Lower Columbia River
Cowlitz River
Klickitat River
Kalama River
Lewis River
Wind River
Little White Salmon River
White Salmon River
Herman Creek
Tanner Creek
Eagle Creek
Sandy River
Hood River
Deschutes River
Dam Location
Temperature Difference Between Columbia River and Tributary
Tributary temperatures warmer than the Columbia
Tributary temperatures between 0*C and 2*C cooler than the Columbia
Tributary temperatures between 2*C and 4*C cooler than the Columbia
Tributary temperatures > 4*C cooler than the Columbia
100

26 CWR Tributaries in the Lower Columbia River

Tributary Name	River Mile	Mainstem Temp[1]	Tributary Temp[2]	Temp Difference	Tributary Flow[3]	Plume CWR Volume (> 2°C Δ)[4]	Stream CWR Volume (> 2°C Δ)[5]	Total CWR Volume (> 2°C Δ)
		°C	°C	°C	cfs	m3	m3	m3
Skamokawa Creek	31	21.3	16.2	-5.1	23	450	1,033	1,483
Mill Creek	51	21.3	14.5	-6.8	10	110	446	556
Abernethy Creek	52	21.3	15.7	-5.6	10	81	806	887
Germany Creek	54	21.3	15.4	-5.9	8	72	446	518
Cowlitz River	65	21.3	16.0	-5.4	3634	870,000	684,230	1,554,230
Kalama River	71	21.3	16.3	-5.0	314	14,000	57,089	71,089
Lewis River	84	21.3	16.6	-4.8	1291	120,000	493,455	613,455
Sandy River	117	21.3	18.8	-2.5	469	9,900	129,372	139,272
Washougal River[4]	118	21.3	19.2	-2.1	107	740	32,563	33,303
Bridal Veil Creek	129	21.3	11.7	-9.6	7	120	0	120
Wahkeena Creek	132	21.3	13.6	-7.7	15	220	0	220
Oneonta Creek	134	21.3	13.1	-8.2	29	820	54	874
Woodward Creek	138	21.3	16.8	-4.4	11	64	0	64
McCord Creek	139	21.3	11.7	-9.6	15	380	0	380
Moffett Creek	140	21.3	12.8	-8.5	9	140	0	140
Tanner Creek	141	21.3	11.7	-9.6	38	1,300	413	1,713
Bonneville Dam								
Eagle Creek	143	21.2	15.1	-6.1	72	2,100	888	2,988
Rock Creek	147	21.2	17.4	-3.8	47	530	1,178	1,708
Herman Creek	147	21.2	12.0	-9.2	45	168,000	1,698	169,698
Wind River	151	21.2	14.5	-6.7	293	60,800	44,420	105,220
Little White Salmon River	159	21.2	13.3	-7.9	88	1,097,000	4,126	1,101,126
White Salmon River	165	21.2	15.7	-5.5	715	72,000	81,529	153,529
Hood River	166	21.4	15.5	-5.9	374	28,000	0	28,000
Klickitat River	177	21.4	16.4	-5.0	851	73,000	149,029	222,029
The Dalles Dam								
Deschutes River	201	21.4	19.2	-2.2	4772	300,000	580,124	880,124
John Day Dam								
Umatilla River[4]	285	20.9	20.8	-0.1	169	0	46,299	46,299

[1] August Mean (10 year average) from nearest station in DART.

[2] August Mean (NorWeST model estimate).

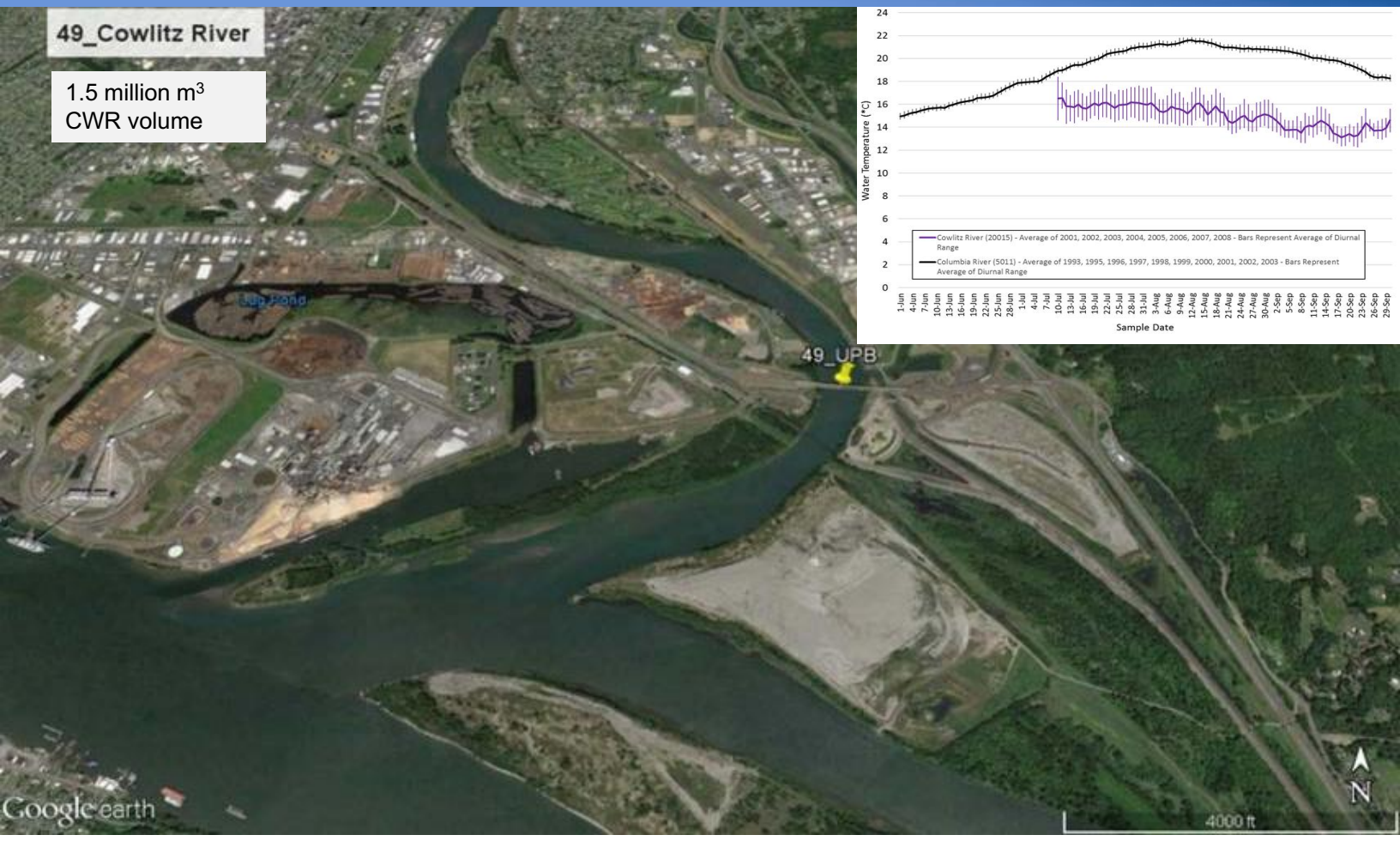
[3] August Mean (EROM model; USGS gage for Kalama, Lewis, Washougal, White Salmon, Klickitat, and Deschutes)

[4] Washougal and Umatilla only provide intermitent CWR; CWR volume for when >2C colder than Columbia River.

CWR Volume Methods

1. Upstream extent of CWR use
   - First geomorphic feature (Google earth)
   - Pit tag/Radio telemetry data
   - Site investigation (depth measurement 0.8m criteria)
   - Discussions with field biologists
2. Stream CWR volume calculation
   - Stream length x Average cross-sectional area
3. CWR plume/cove calculation
   - Cormix Model
   - Field Sampling and ArcGIS
     - Wind River, Herman Creek Cove, Drano Lake

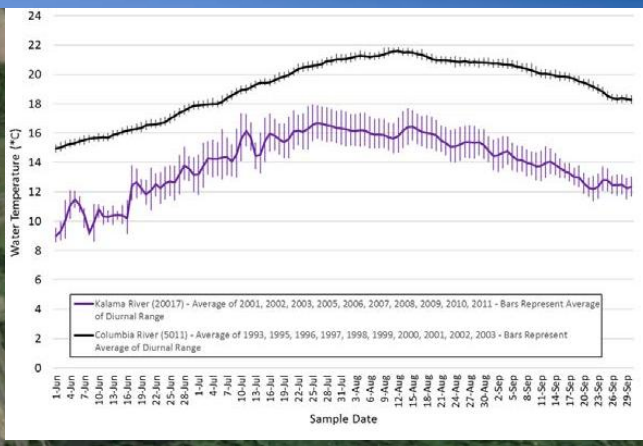
Cowlitz River CWR



Kalama River CWR

52_Kalama River

71,000 m^3 CWR volume



52_UPB

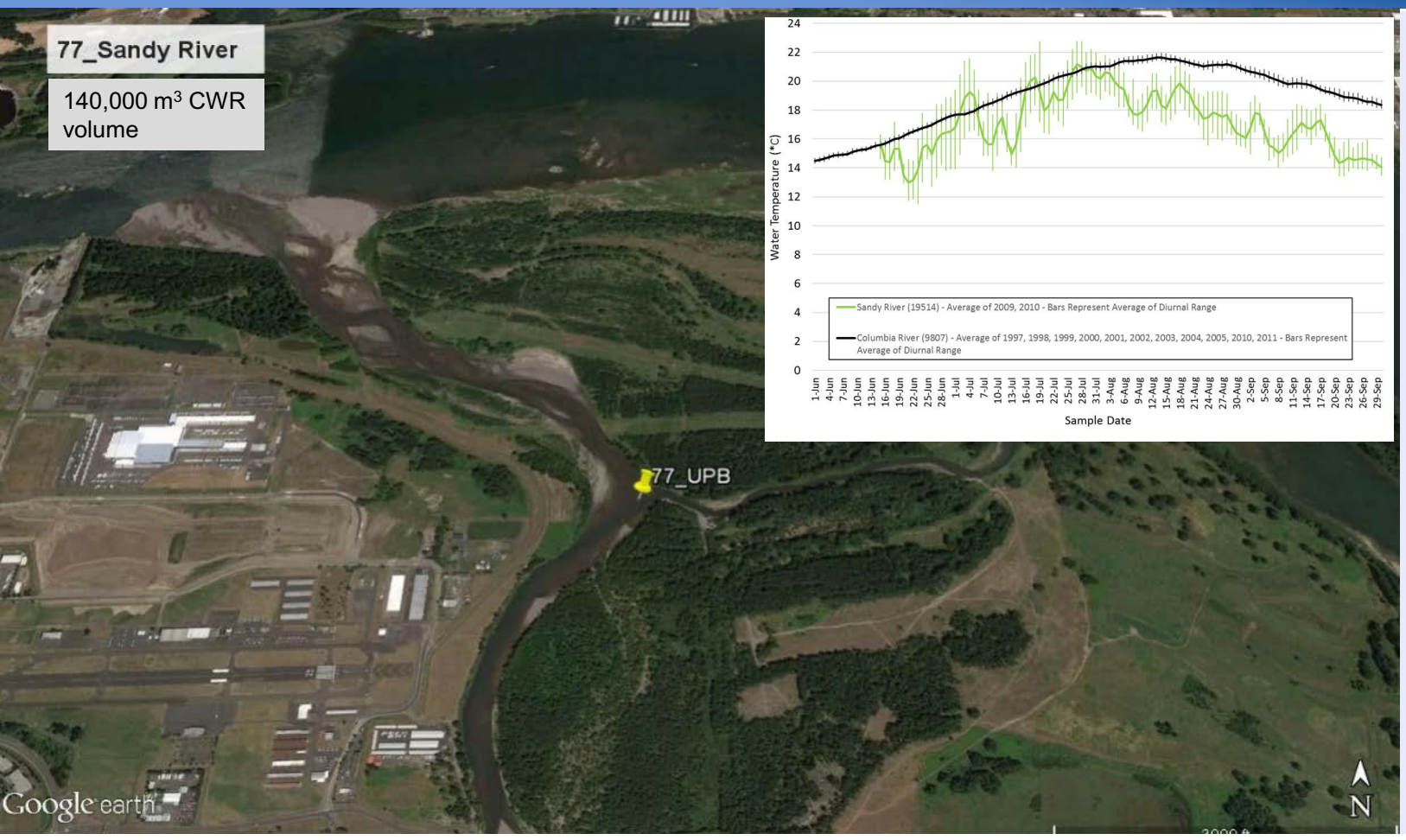
Google earth

1000 ft

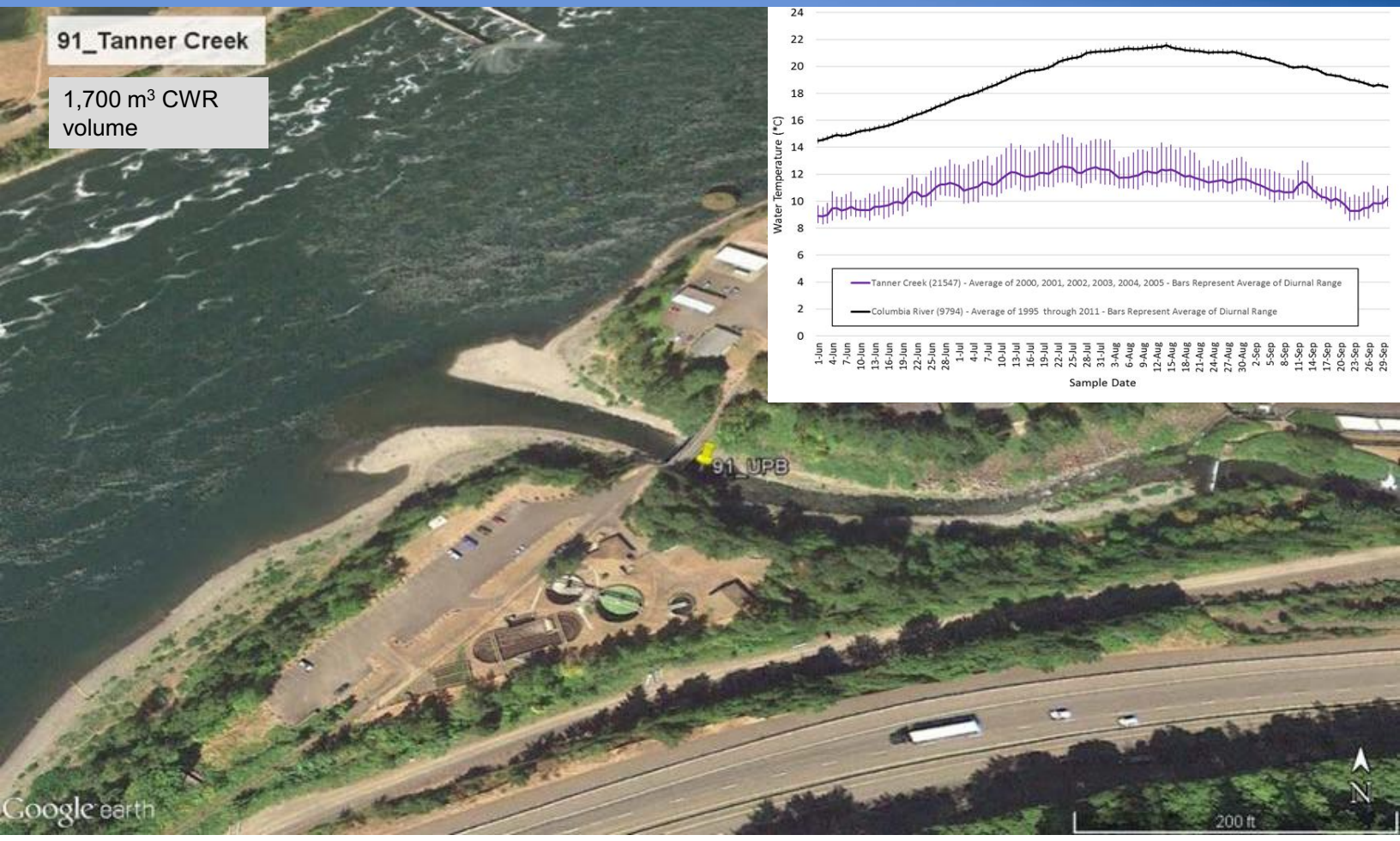
N

Lewis River CWR

Sandy River CWR



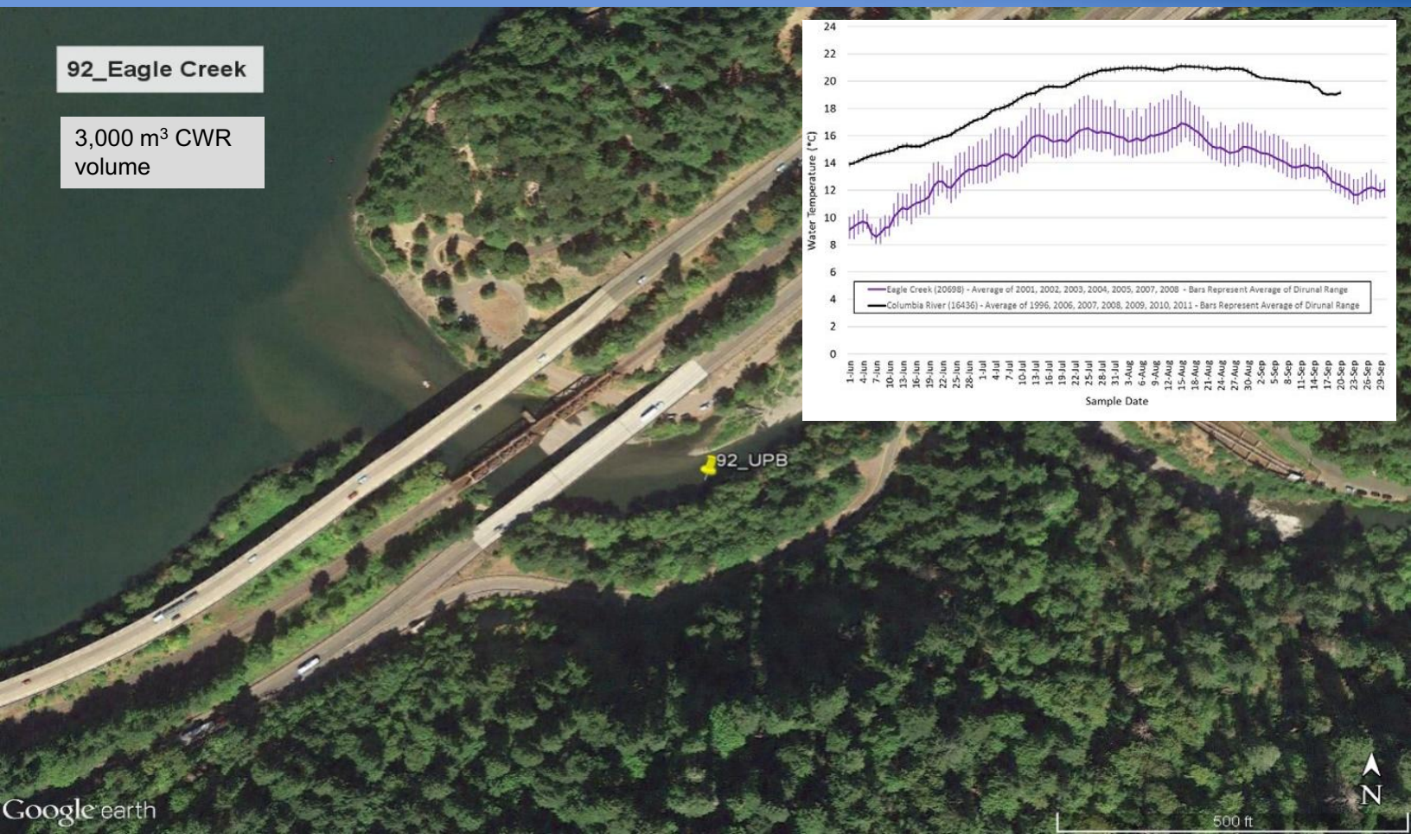
Tanner Creek CWR



Eagle Creek CWR

92_Eagle Creek

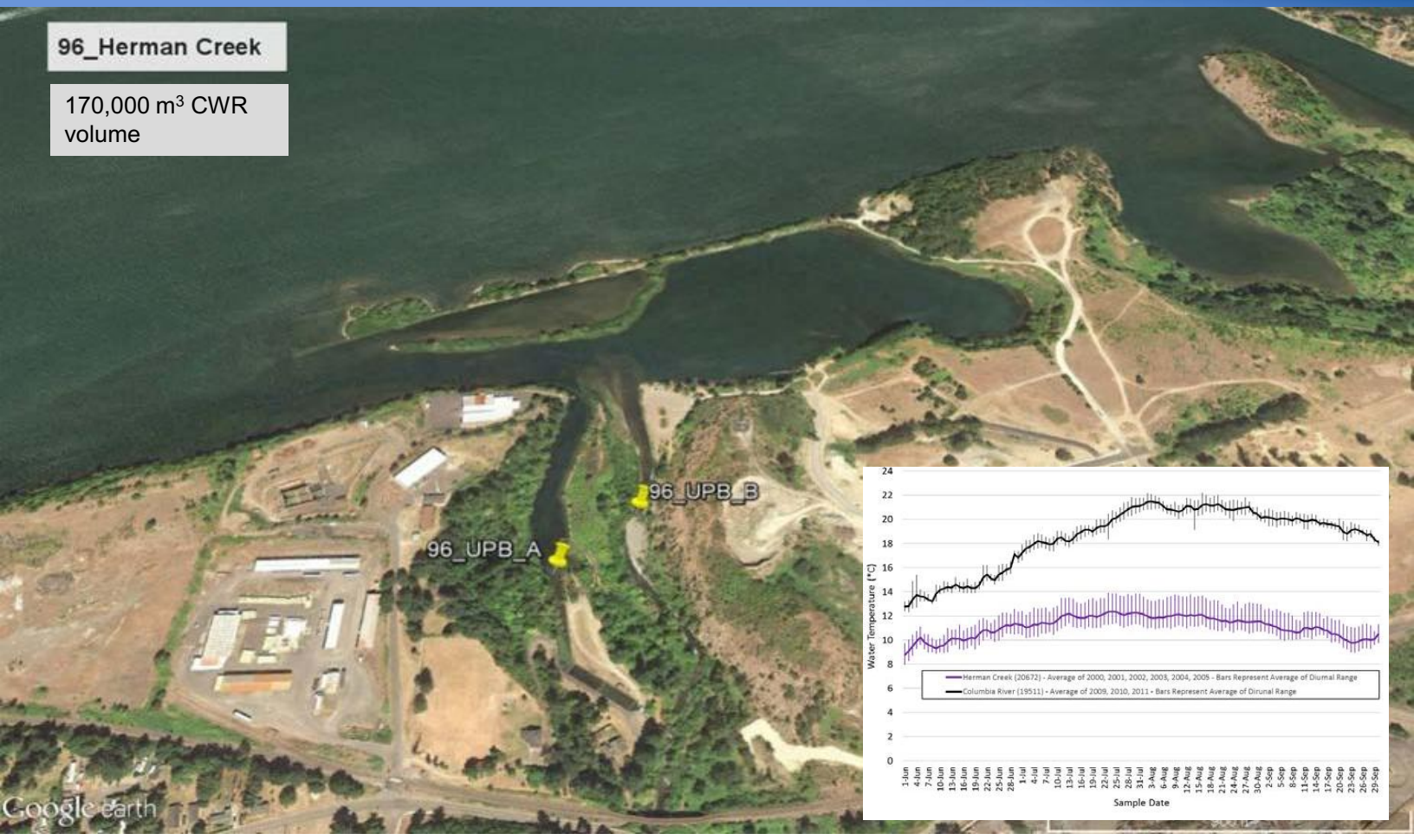
3,000 m^3 CWR volume



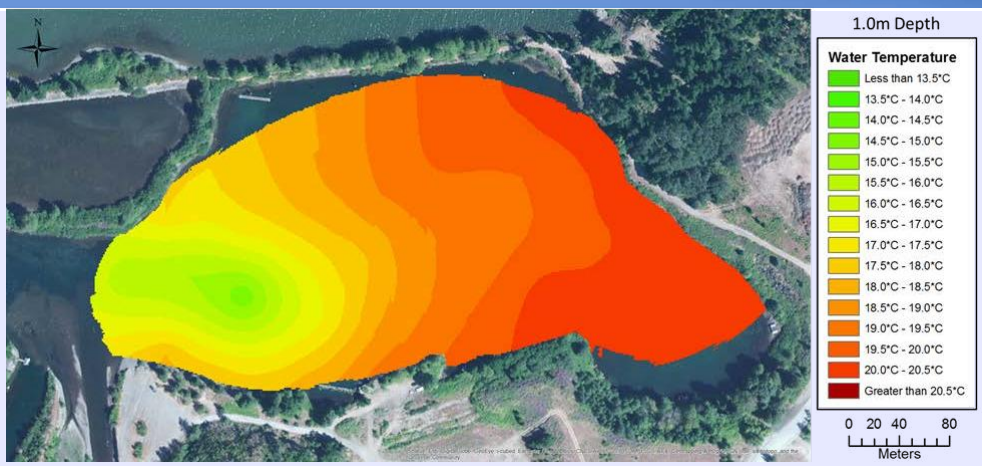
Herman Creek/Cove CWR

96_Herman Creek

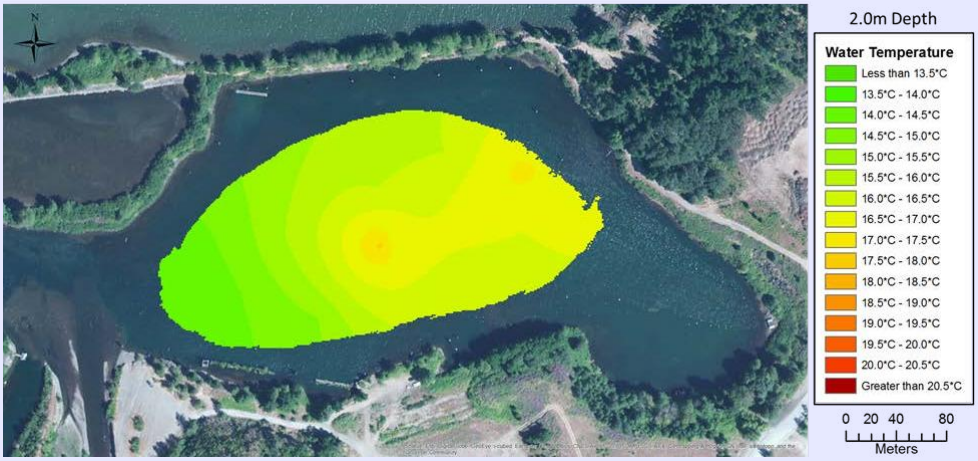
170,000 m^3 CWR volume



Herman Creek/Cove CWR

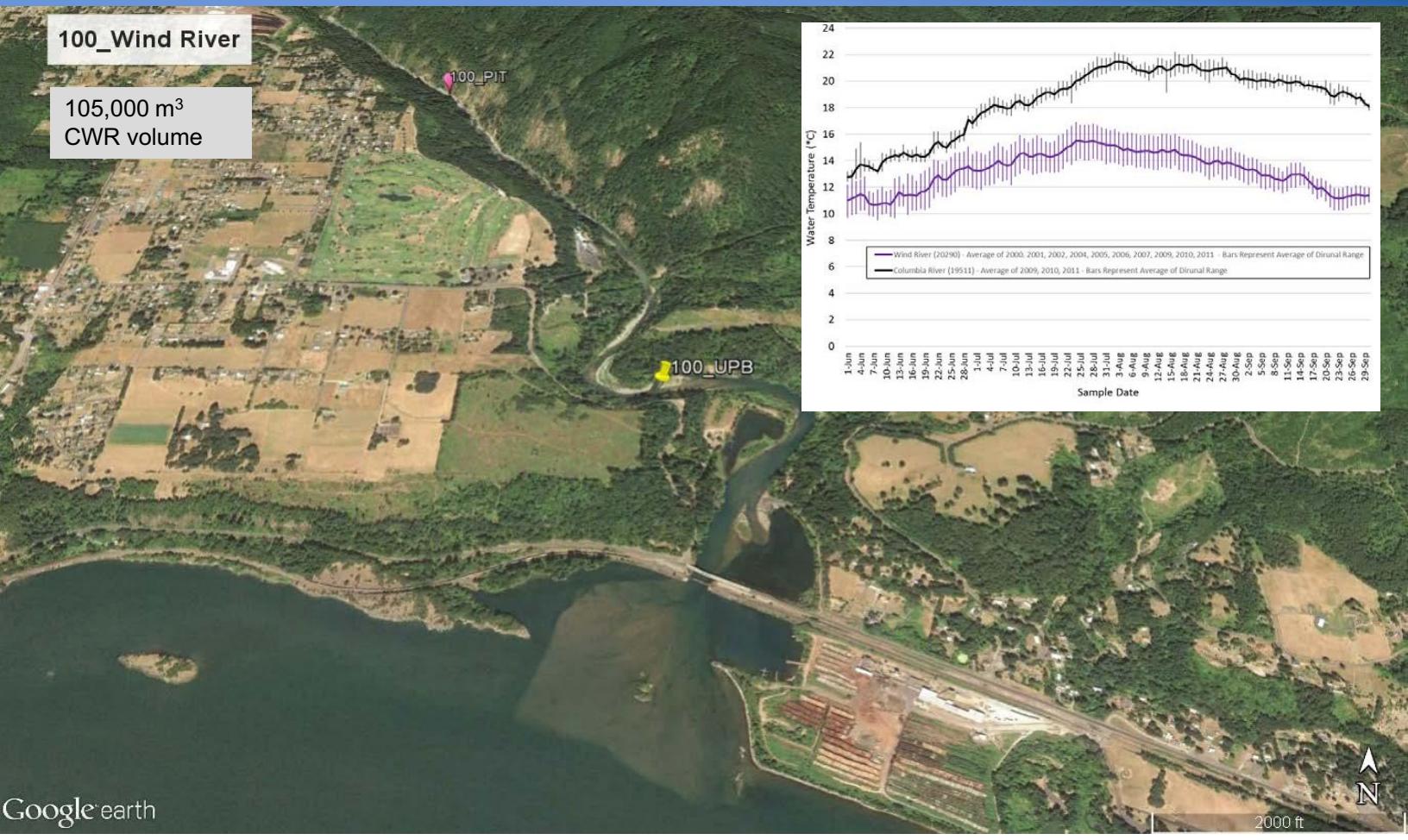


1 meter depth

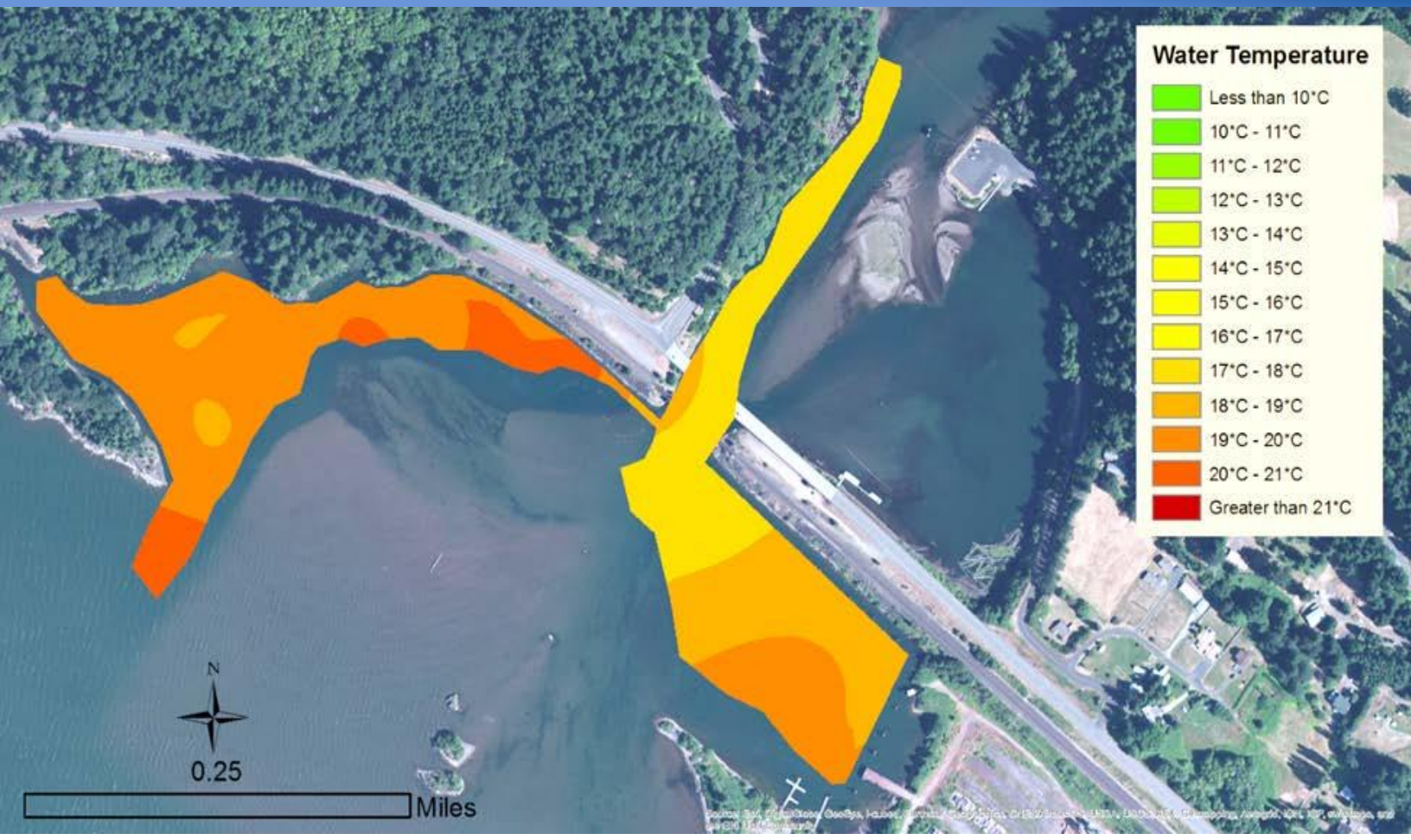


2 meter depth

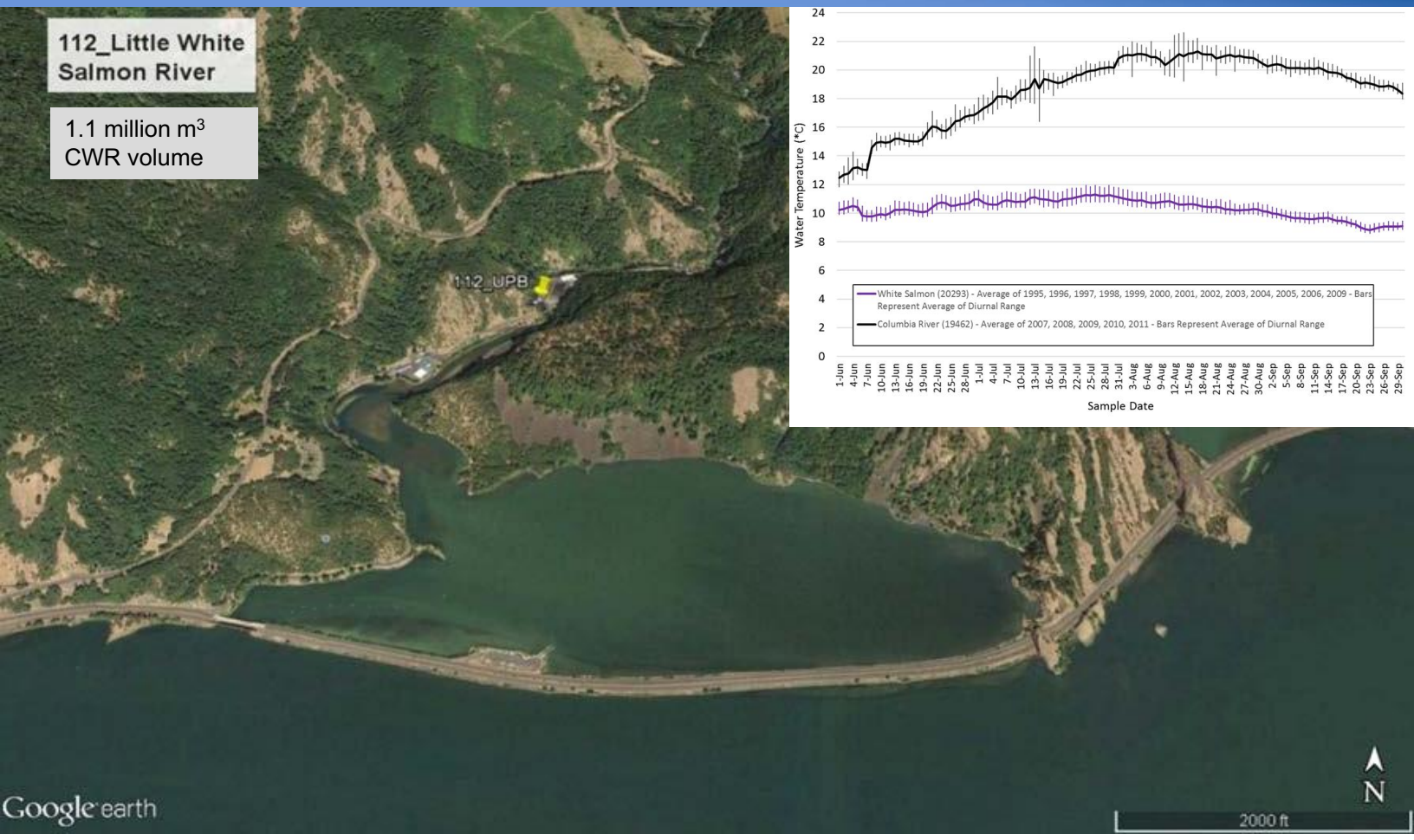
Wind River CWR



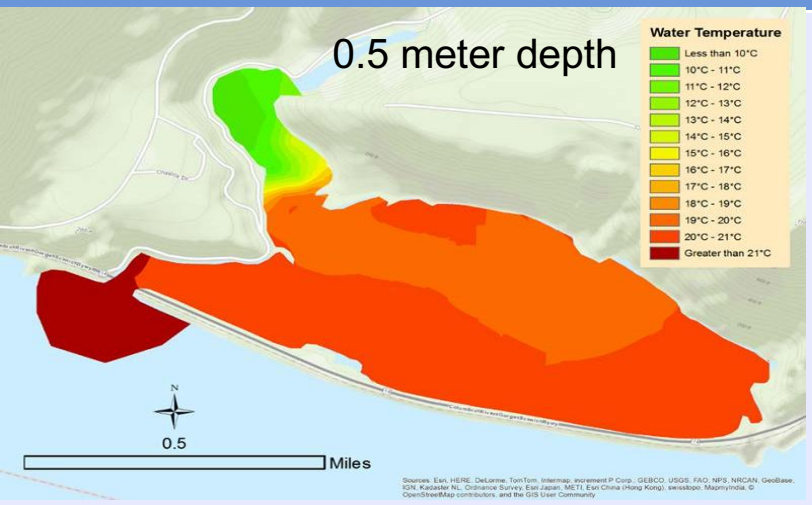
Wind River CWR

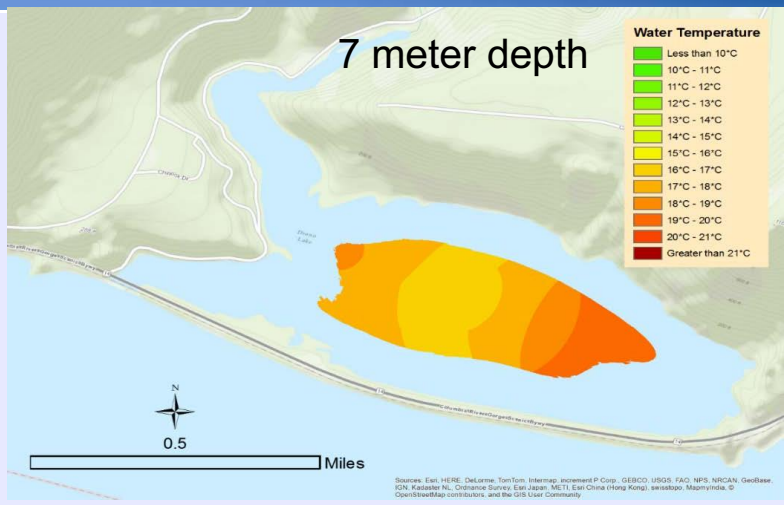


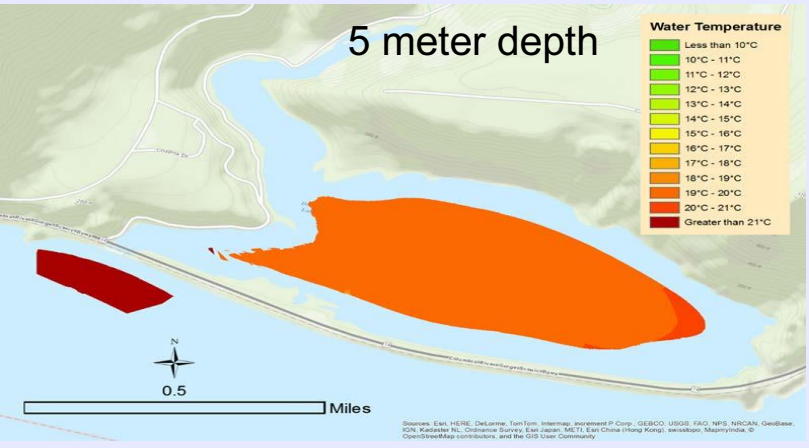
Little White Salmon River/Drano Lake CWR

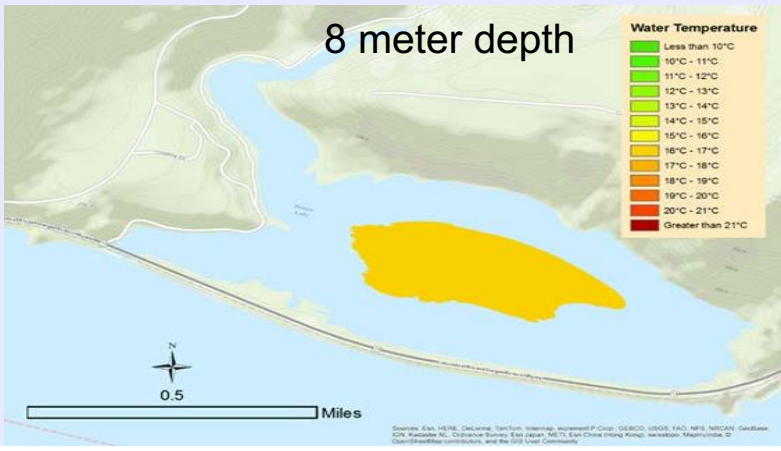


Little White Salmon River/Drano Lake CWR







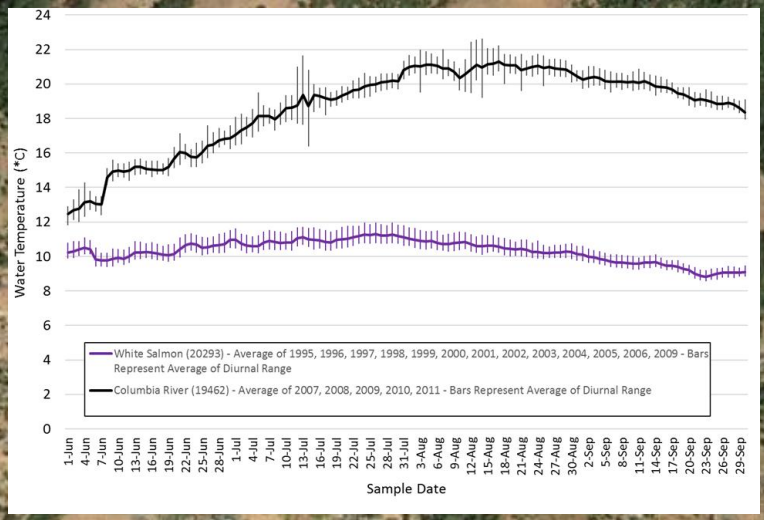


White Salmon River CWR

115_White Salmon River

115_UPB

150,000 m^3 CWR volume

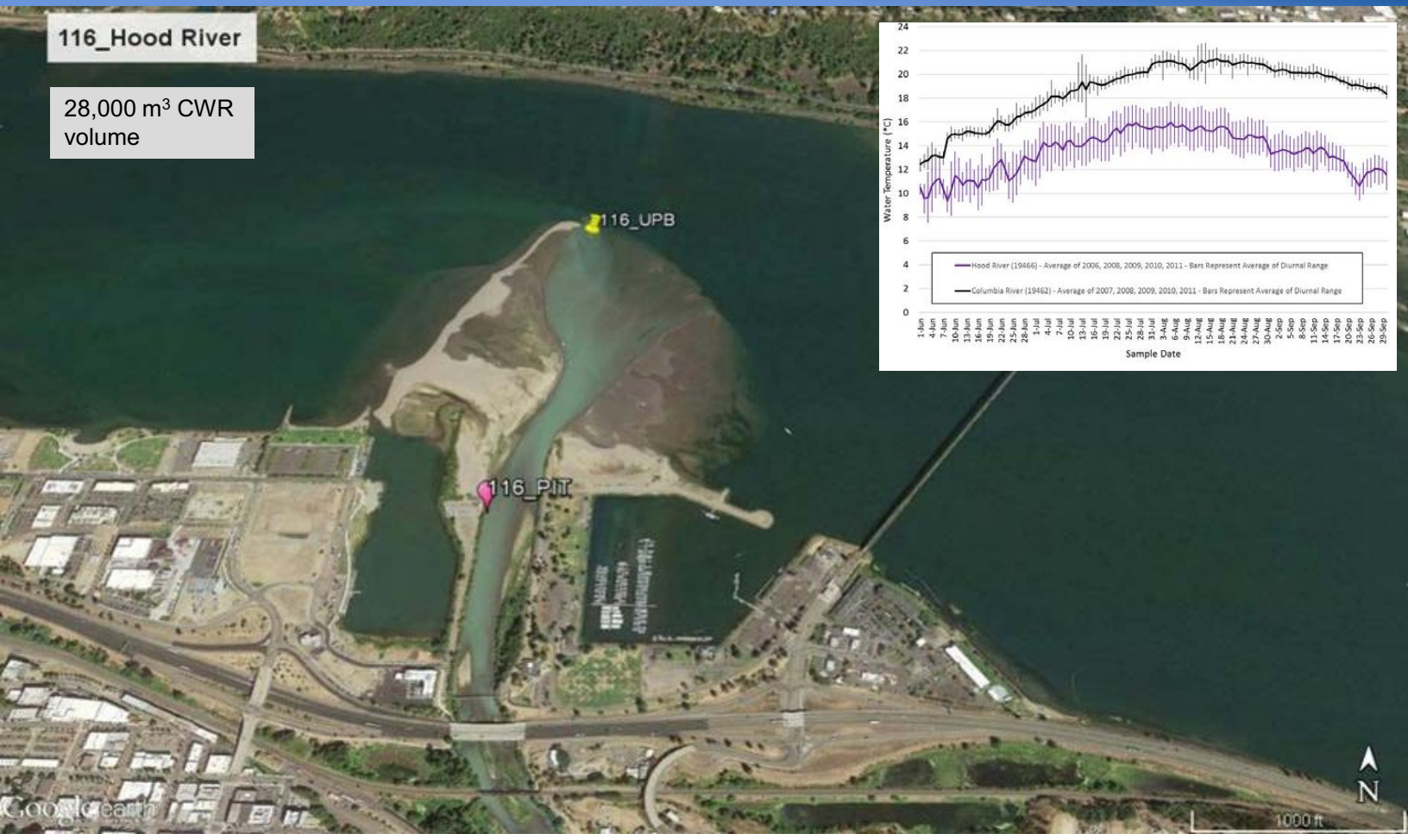


Google earth

N

2000 ft

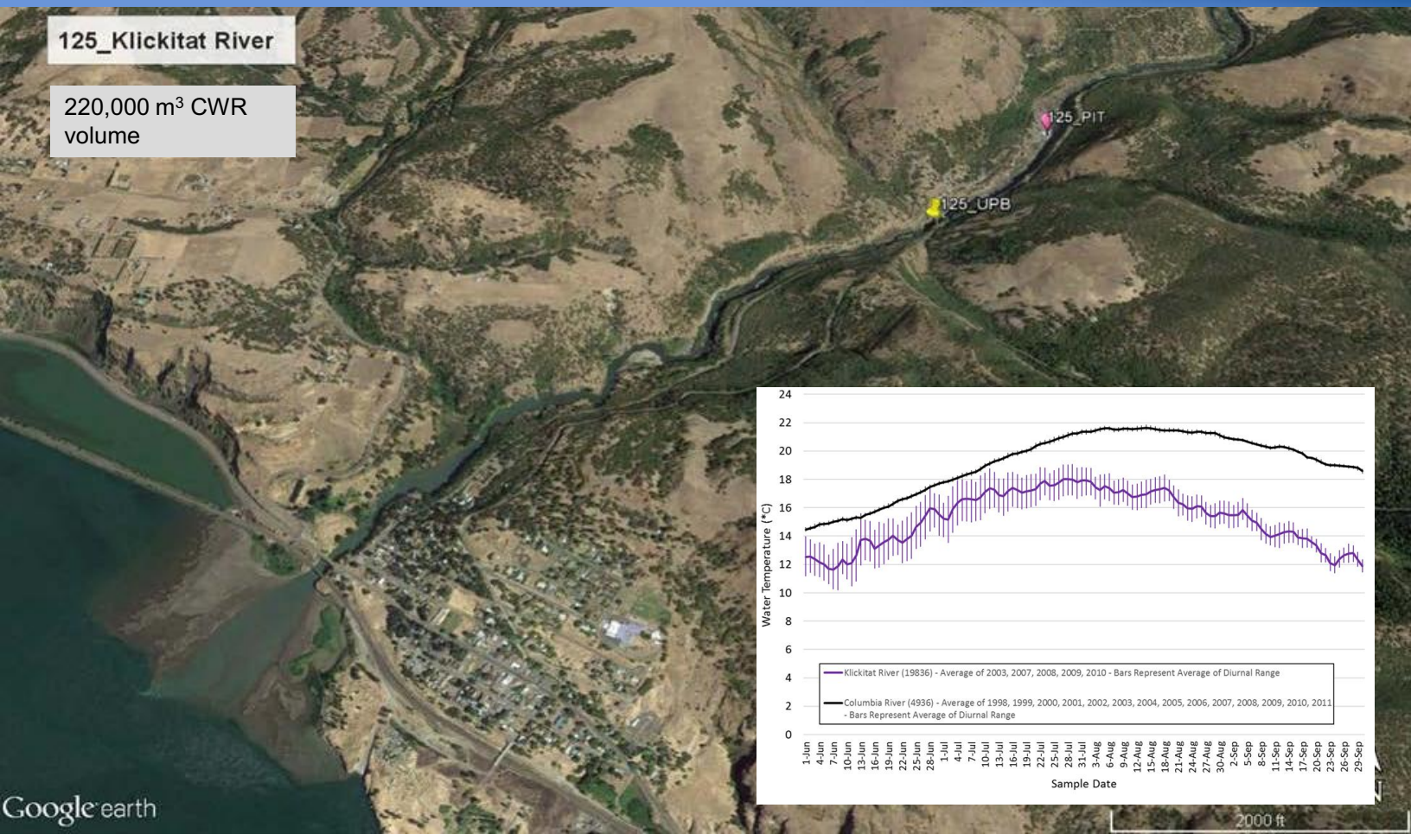
Hood River CWR



Klickitat River CWR

125_Klickitat River

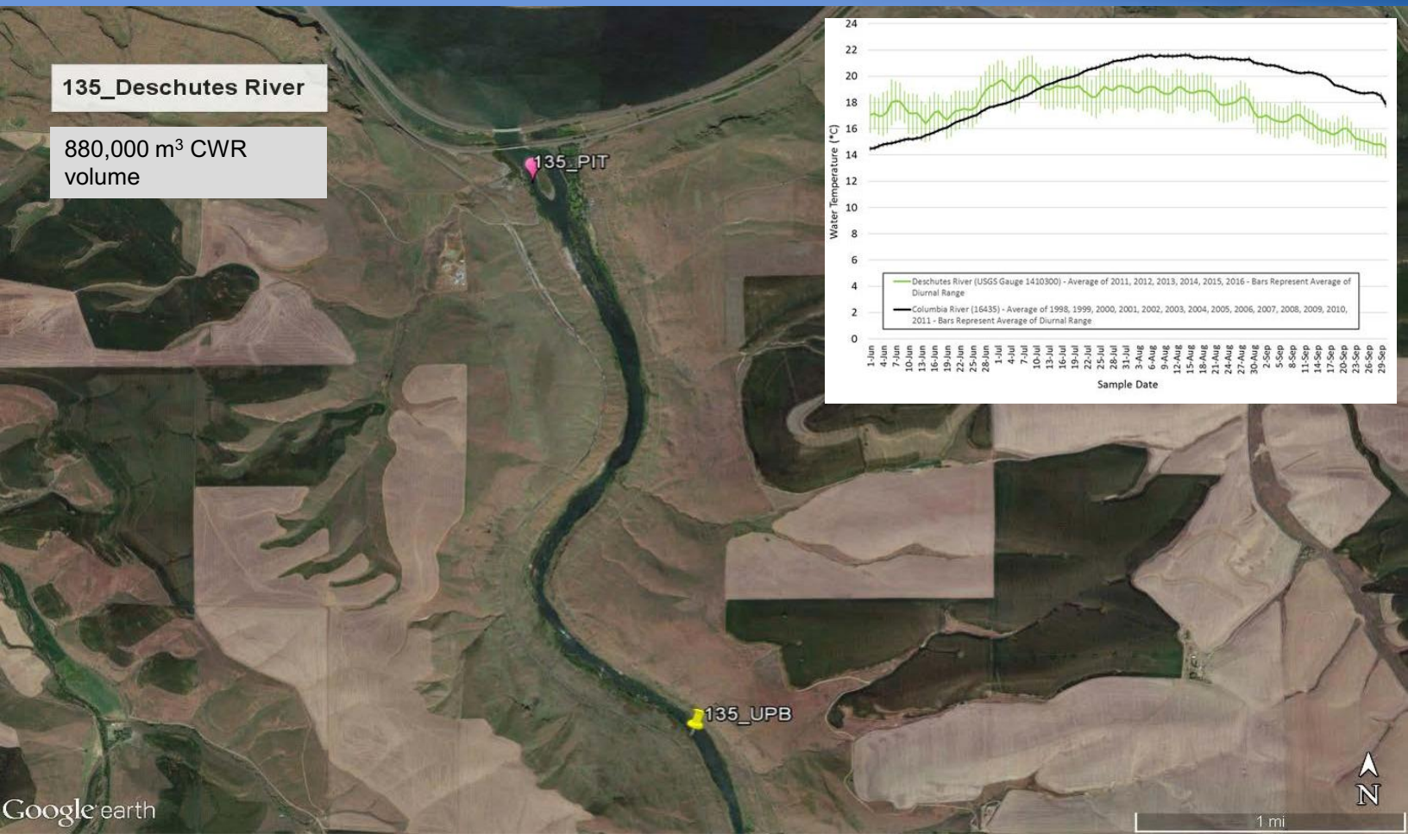
220,000 m^3 CWR volume



Deschutes River CWR

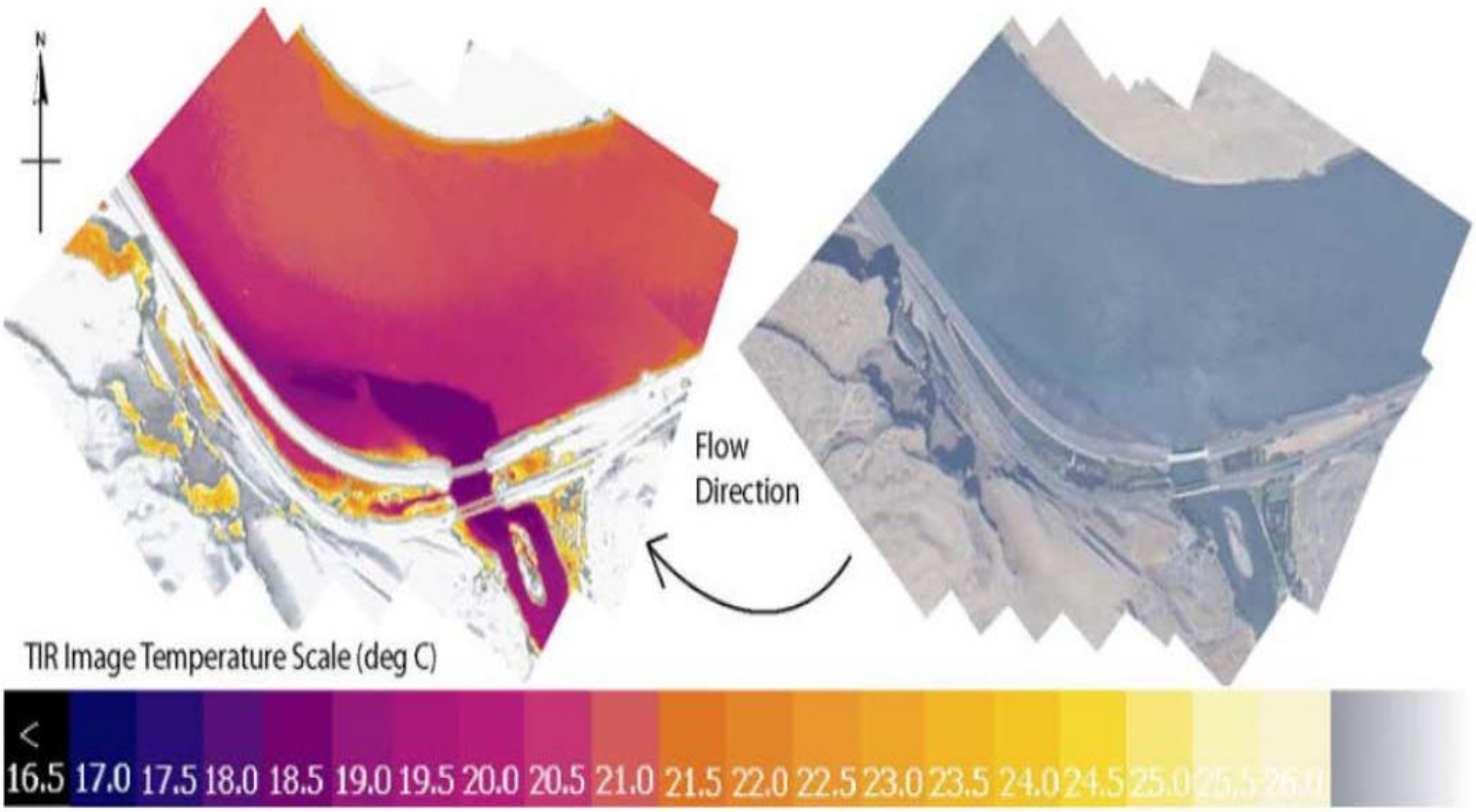
135_Deschutes River

880,000 m^3 CWR volume



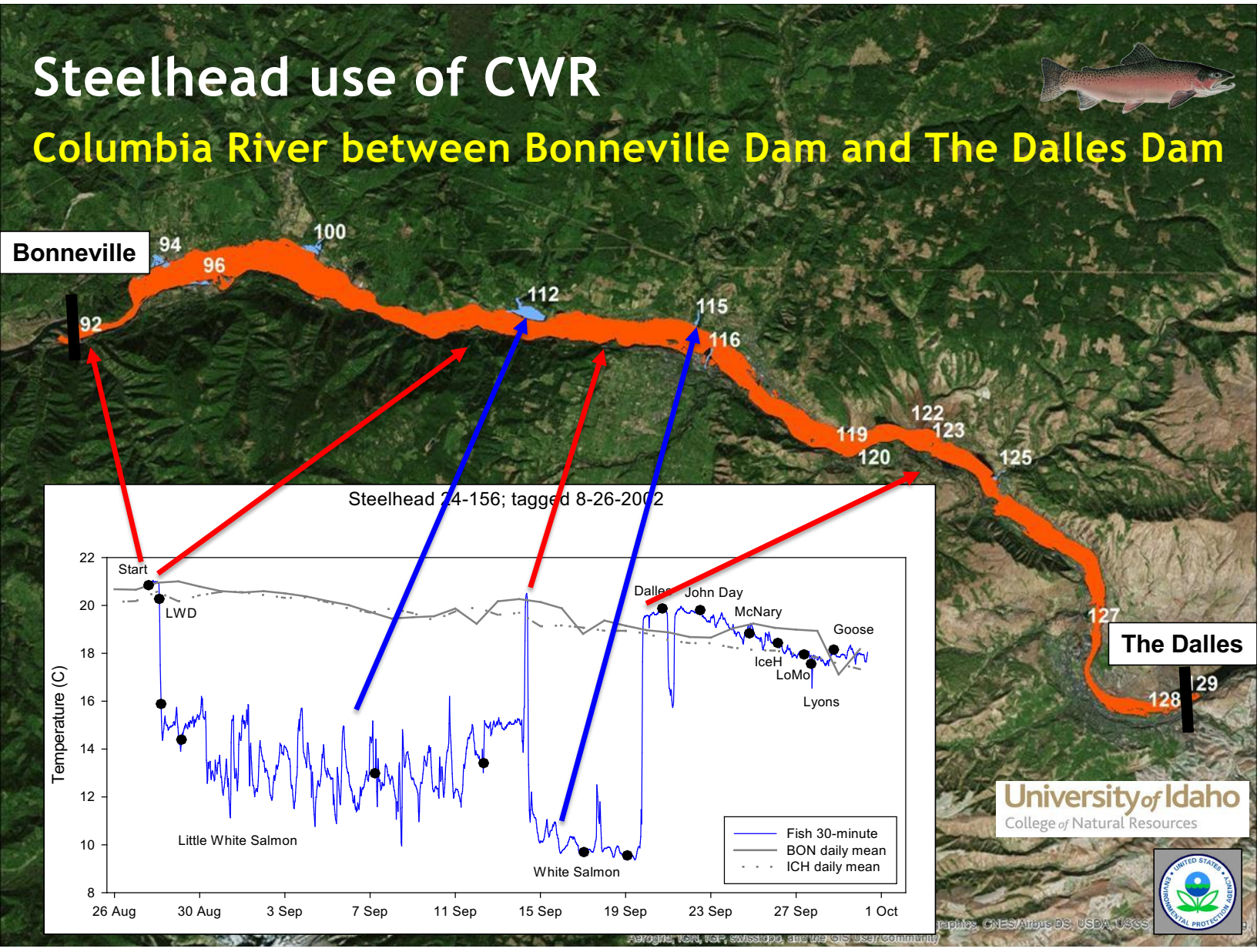
Deschutes River CWR Plume

Source: Watershed Sciences LLC, 2003



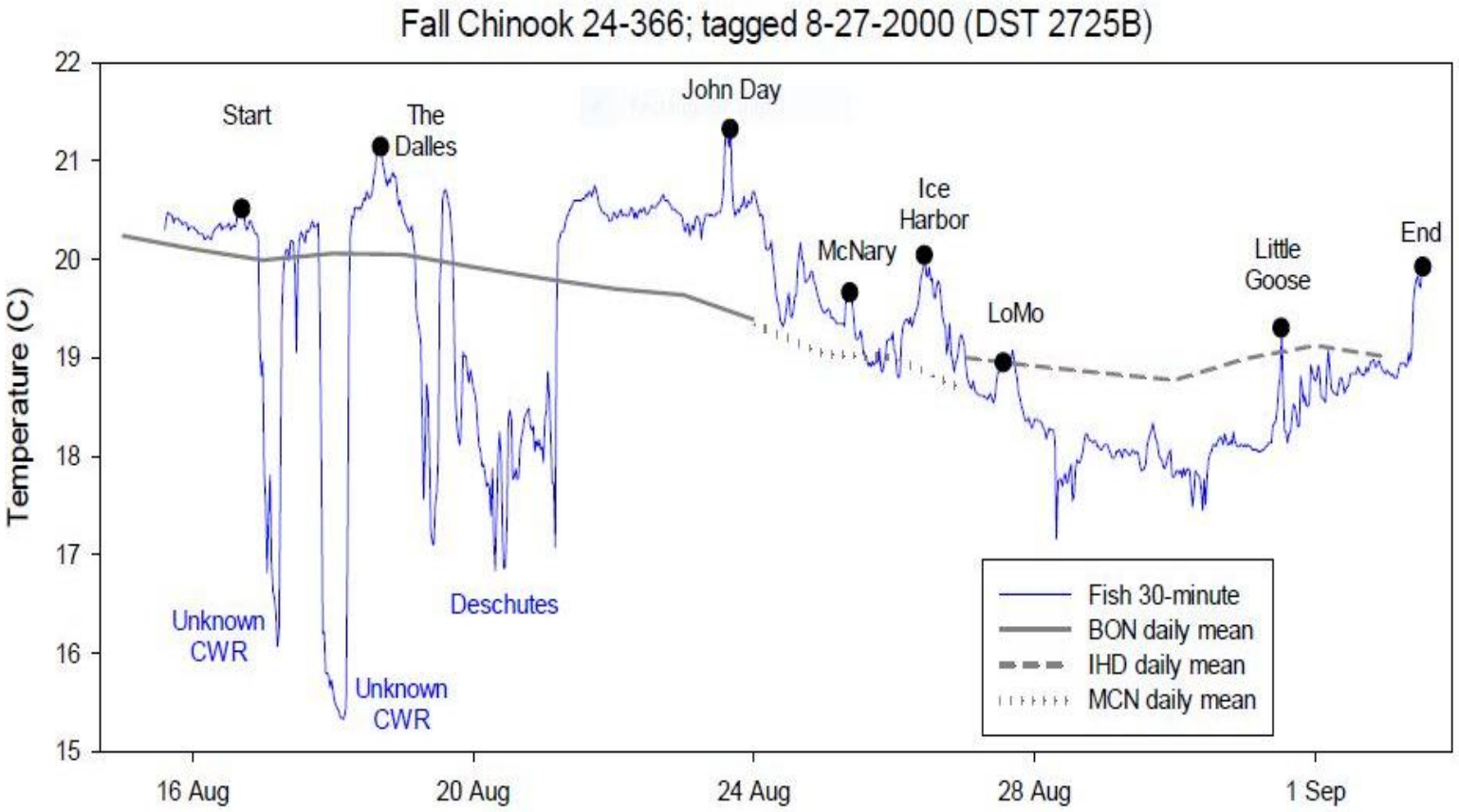
Steelhead use of CWR

Columbia River between Bonneville Dam and The Dalles Dam

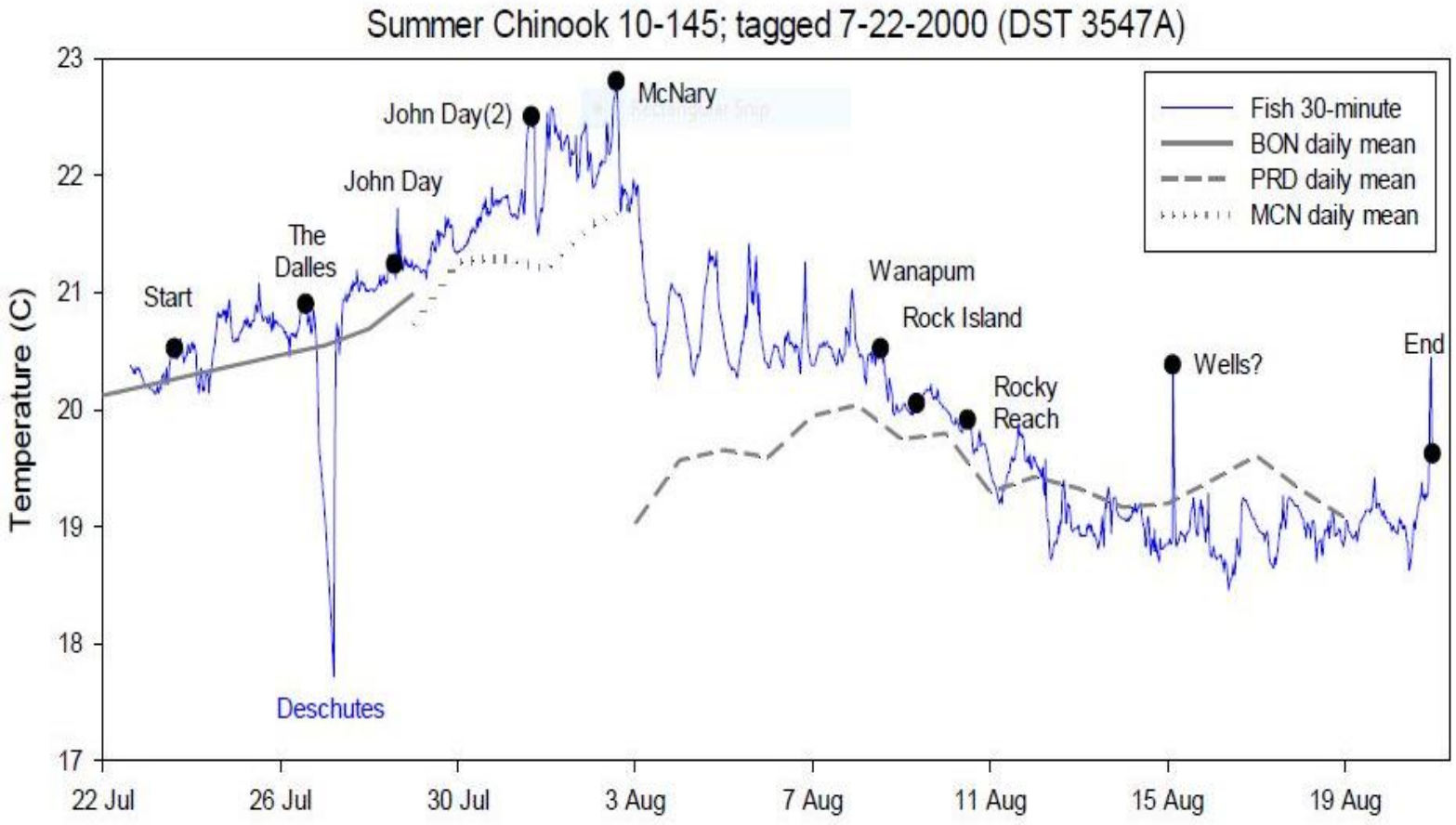


Fall Chinook use of CWR example

University of Idaho
College of Natural Resources



Summer Chinook CWR use example



Steelhead population use of specific CWR areas in the Columbia River

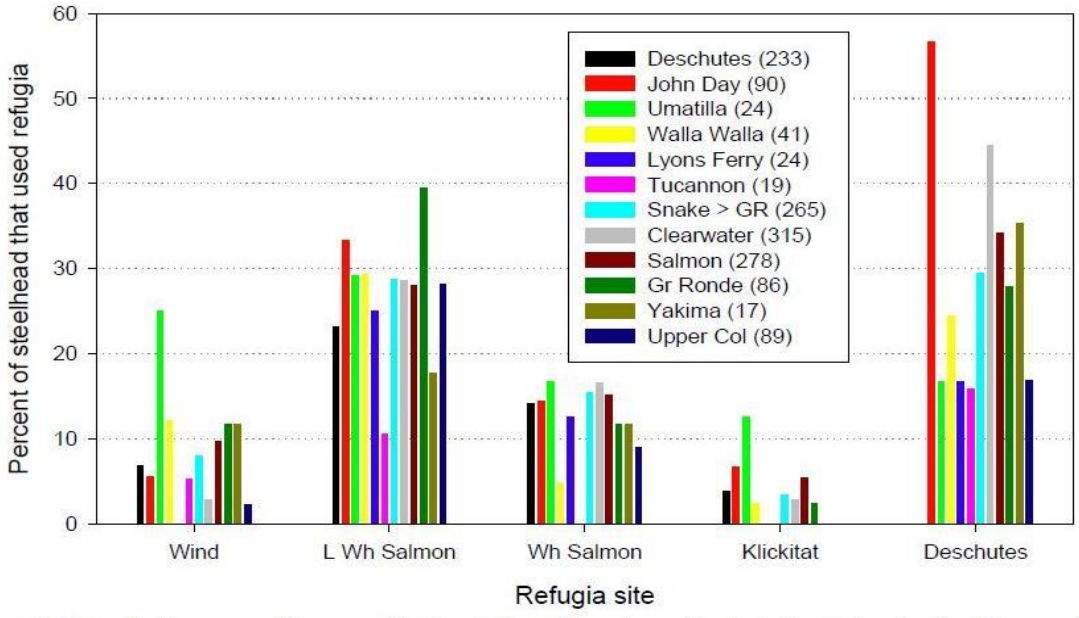


Figure 7. Population-specific use of selected cool-water refugia tributaries in the Bonneville-John Day reach by radio-tagged summer steelhead in 1996-1997 and 2000. Bar colors represent upriver populations, with sample sizes in parentheses. Steelhead additionally used Herman and Eagle creeks, but these small sites were inconsistently monitored in these study years. A small number of steelhead temporarily used the Hood River (not shown).

Source - Keefer et. al. 2011

Steelhead populations that migrate in heat of the summer use CWR the most

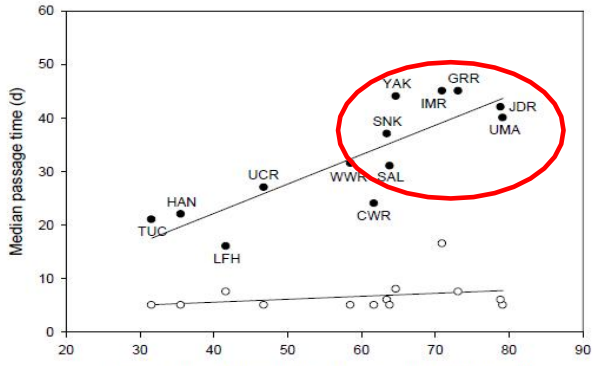


Figure 8. Relationships between median population-specific steelhead passage times from the top of Bonneville Dam to the top of John Day Dam and the percentages of steelhead that were (•) or were not (○) recorded in cool-water tributaries for > 12 h. Labels represent specific upriver populations. From Keefer et al. (2009).

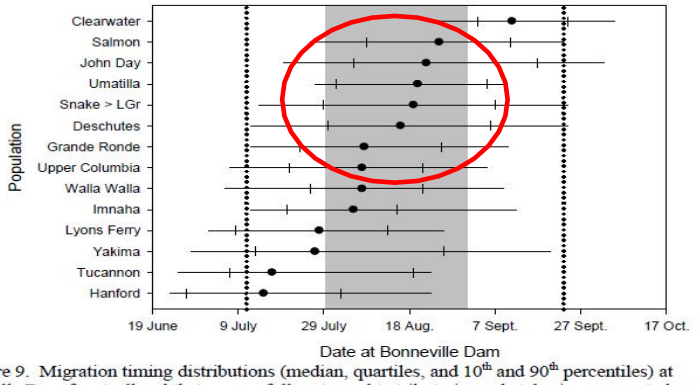


Figure 9. Migration timing distributions (median, quartiles, and 10th and 90th percentiles) at Bonneville Dam for steelhead that successfully returned to tributaries or hatcheries across study years. Vertical dotted lines show mean first and last dates that Columbia River water temperature was 19 °C; the shaded area shows dates with mean temperature ≥21 °C. From Keefer et al. (2009).

Populations migrating during peak August temperature use CWR the most

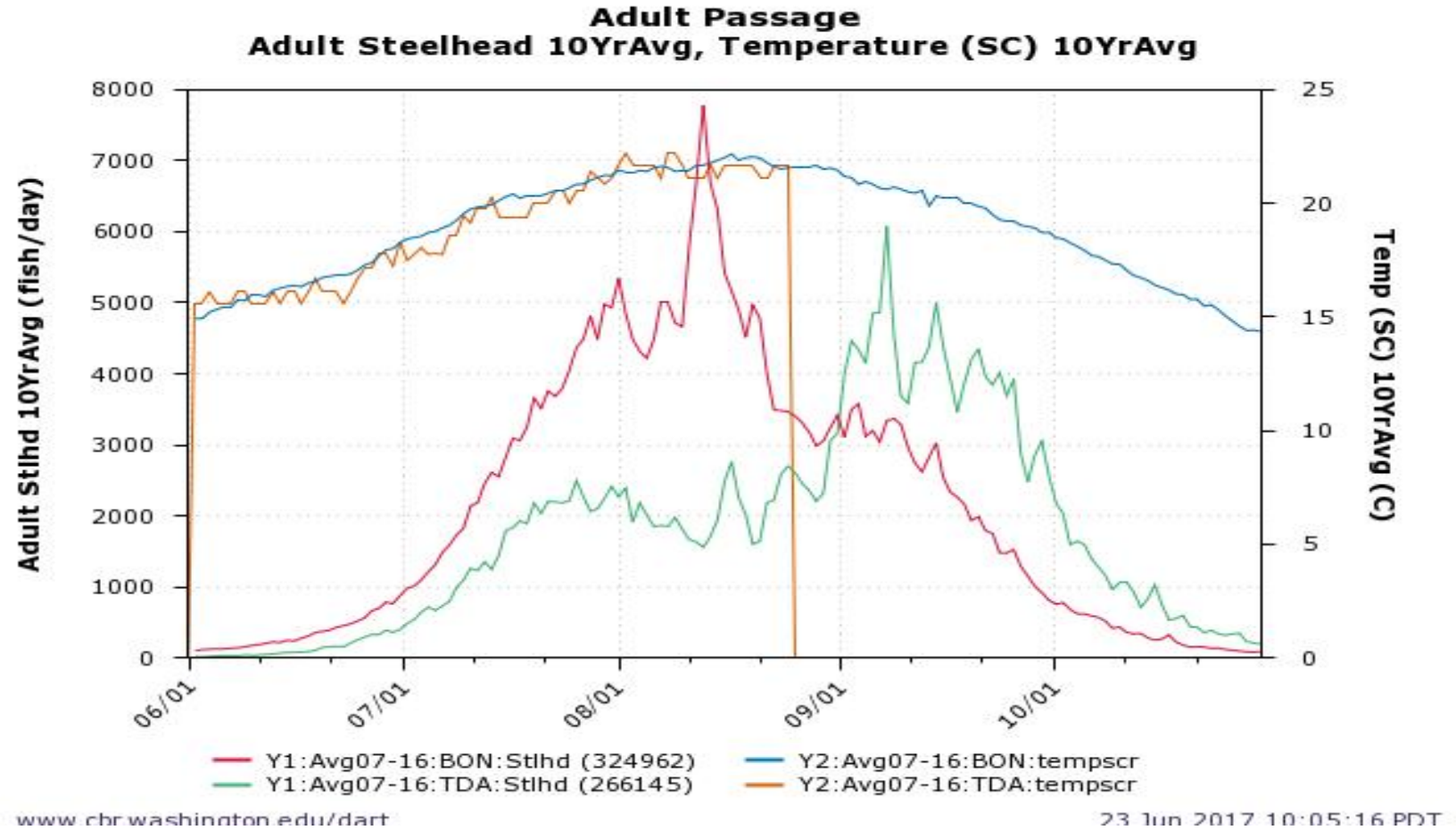
- ✓ John Day
- ✓ Umatilla
- ✓ Grande Ronde
- ✓ Snake River
- ✓ Salmon
- ✓ Imnaha

Less CWR use for populations that migrate early

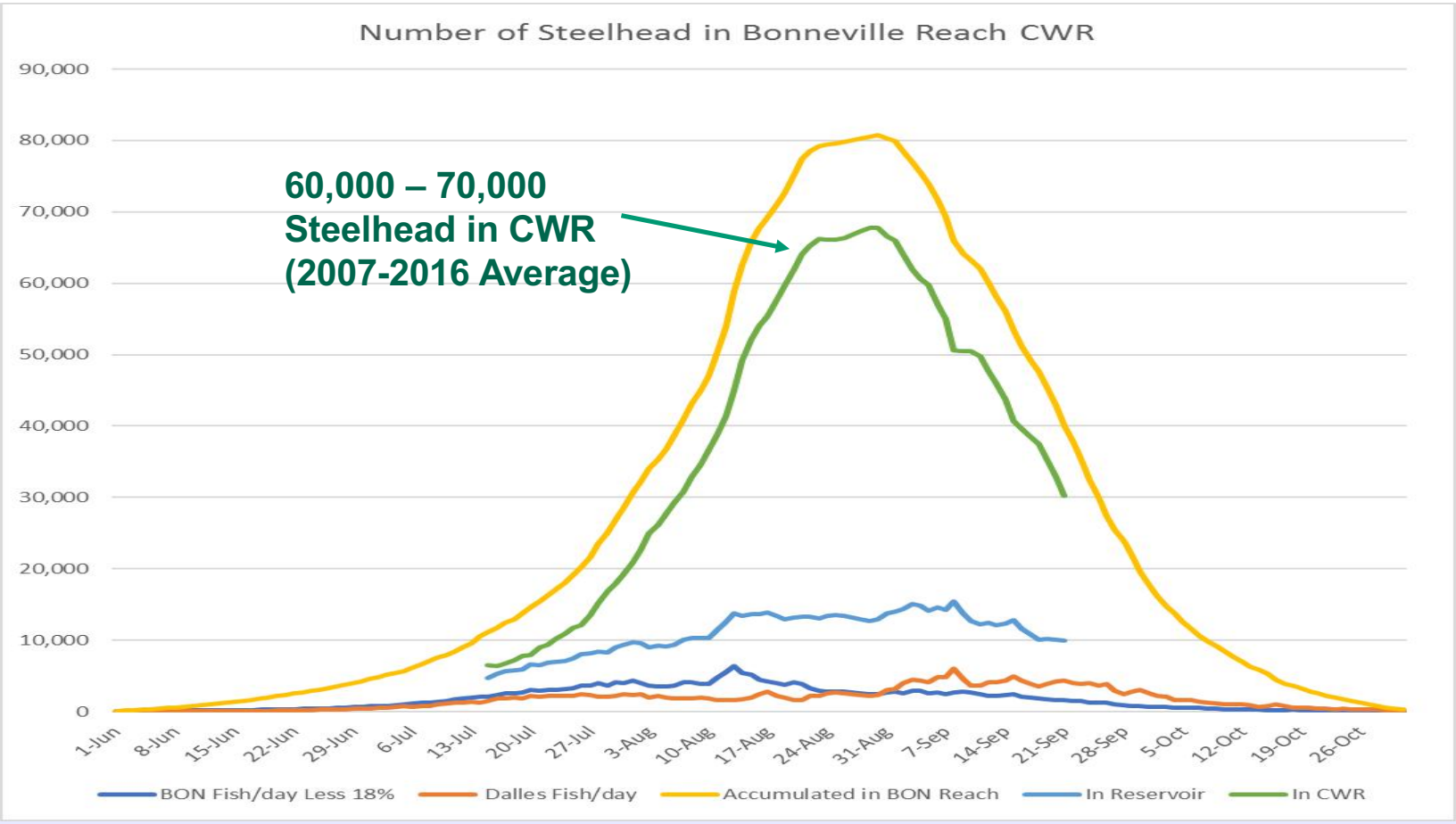
- ✓ Hanford
- ✓ Tucannon
- ✓ Upper Columbia

Source - Keefer et al. 2011

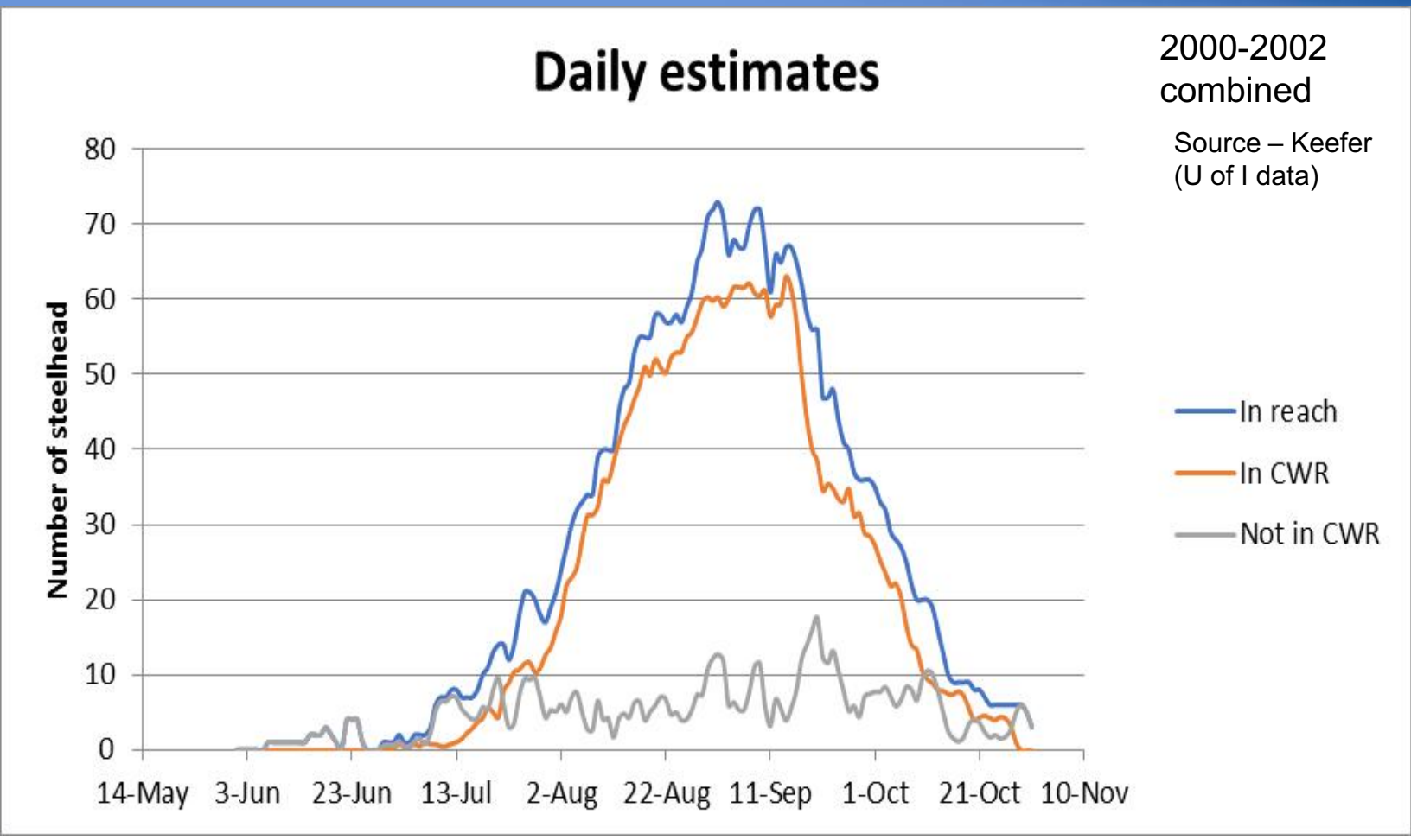
Bonneville Dam vs The Dalles Dam Steelhead Passage



Accumulation of Steelhead in Bonneville Reservoir Reach



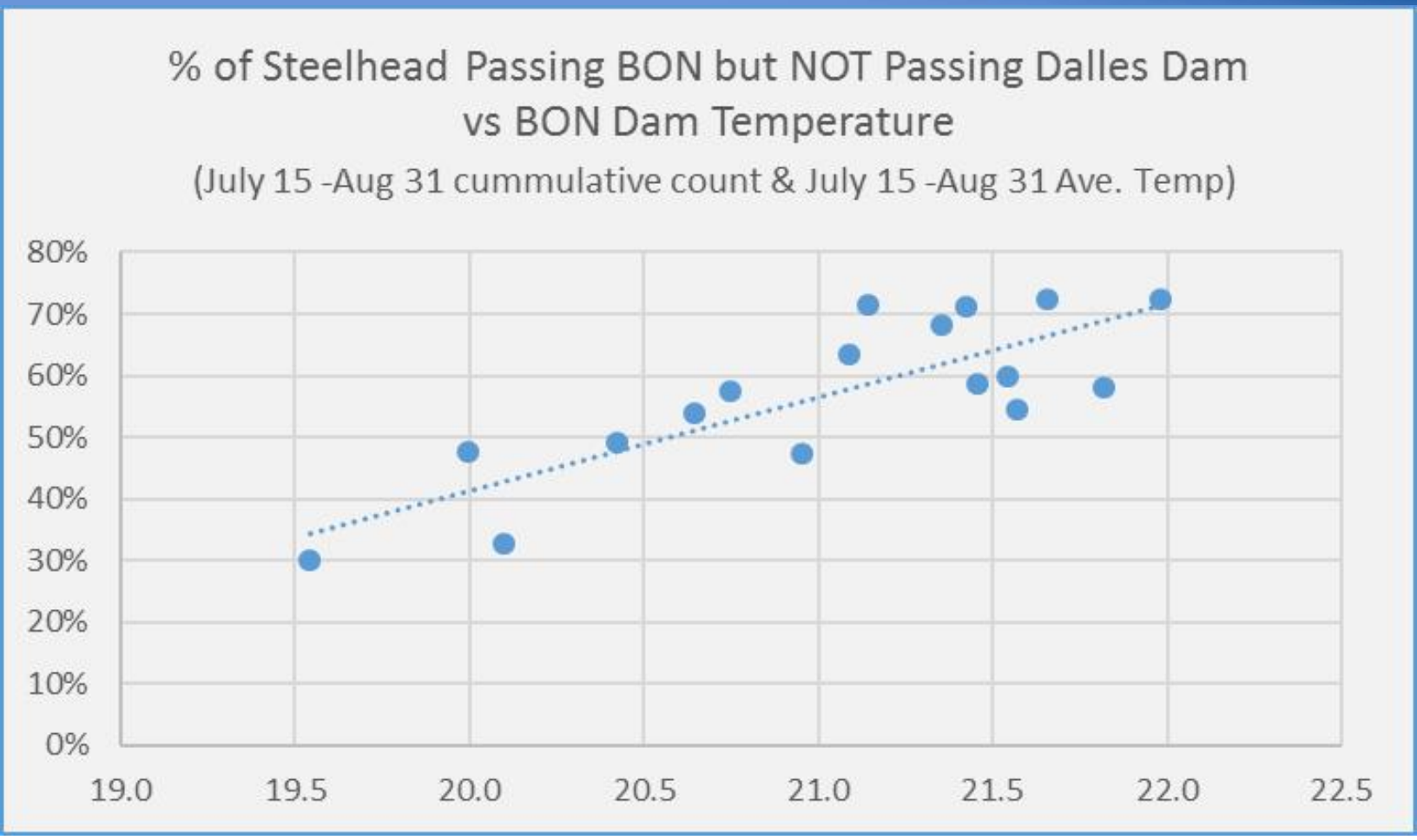
Distribution of 219 Radio-tagged Steelhead in Bonneville Reach



Inter-Annual Variation of the # of Steelhead in Bonneville Reach CWR

Year	Ave Temp July 15 -Aug 31	Passed BON July 15 -Aug 31	Passed Dalles July 15 -Aug 31	Measured % That Passed Dalles June 1-Oct 31	Expected to Passed Dalles July 15 -Aug 31	In BON Reach Peak	In CWR (85%) Peak
2016	21.4	83,919	24,212	80%	66,868	42,656	36,258
2015	21.8	165,138	69,059	84%	137,893	68,834	58,509
2014	21.5	175,686	70,488	80%	140,923	70,435	59,869
2013	21.5	166,926	68,949	83%	138,059	69,110	58,743
2012	20.1	142,032	95,612	86%	122,797	27,185	23,107
2011	19.5	252,331	176,573	82%	207,452	30,879	26,248
2010	21.0	231,804	121,974	82%	189,445	67,471	57,350
2009	21.6	451,509	205,163	86%	388,094	182,931	155,492
2008	20.0	225,506	117,044	79%	177,048	60,004	51,004
2007	21.1	229,124	83,820	76%	173,420	89,600	76,160
2006	21.1	187,415	53,379	72%	134,561	81,182	69,005
2005	21.4	175,028	55,866	77%	135,090	79,224	67,340
2004	22.0	155,516	42,744	78%	120,905	78,161	66,437
2003	21.7	209,328	58,083	77%	160,904	102,821	87,398
2002	20.4	257,857	131,121	82%	210,238	79,117	67,250
2001	20.7	397,879	169,554	80%	319,544	149,990	127,491
2000	20.6	164,593	75,954	75%	124,114	48,160	40,936
1999	20.0	136,136	76,782	77%	104,458	27,676	23,524
Average	20.9	219,048	98,363		175,585	77,222	65,639

Bonneville Reach Steelhead Accumulation vs Temperature



The # of Steelhead in Each Bonneville Reach CWR

Tributary Name	Tributary Temp	Total CWR Volume (> 2°C Δ)	% of CWR in BON Reach	# Steelhead in Each CWR (2007-2016 Ave)	# Steelhead in Each CWR High Year (2009)	# Steelhead in Each CWR Low Year (2012)
	°C	m3				
Eagle Creek	15.1	2,988	0.2%	99	260	39
Rock Creek	17.4	1,708	0.1%	57	149	22
Herman Creek	12.0	169,698	9.5%	5,624	14,788	2,198
Wind River	14.5	105,220	5.9%	3,487	9,169	1,363
Little White Salmon River	13.3	1,101,126	61.7%	36,490	95,957	14,260
White Salmon River	15.7	153,529	8.6%	5,088	13,379	1,988
Hood River	15.5	28,000	1.6%	928	2,440	363
Klickitat River	16.4	222,029	12.4%	7,358	19,349	2,875
Total		1,784,298	100%	59,130	155,492	23,107

Distribution of Radio-tagged Steelhead in specific Bonneville Reach CWR

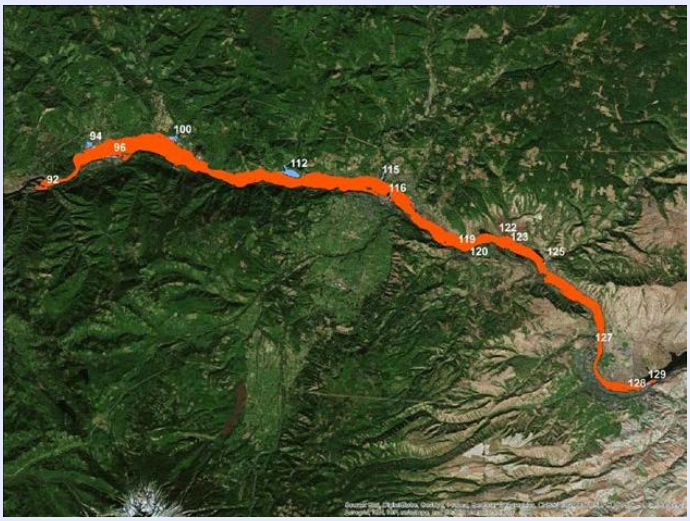
	August 7	August 31	Predicted based on CWR Volume
Below Bonneville Dam	1 (2.9%)	0 (0%)	
Bonneville Reservoir	3 (8.8%)	9 (12.5%)	
Herman Creek	8 (23.5%)	6 (8.3%)	9.5%
Wind River	1 (2.9%)	1 (1.4%)	5.9%
Little White Salmon/Drano Lake	12 (35.3%)	40 (55.6%)	61.7%
White Salmon	3 (8.8%)	4 (5.6%)	8.6%
Klickitat River	4 (11.8%)	4 (5.6%)	12.4%
Unknown CWR	0 (0%)	4 (5.6%)	
The Dalles Dam Tailrace/Fishway	2 (5.9%)	4 (5.6%)	
Total	34 Steelhead	72 Steelhead	

Source – Keefer (U of I data)

- Drano Lake and Herman Creek Cove most used
- Drano Lake highest use in peak accumulation period
- Herman Creek/Cove high use in early accumulation period
- Use of Wind & Klickitat a little less than predicted

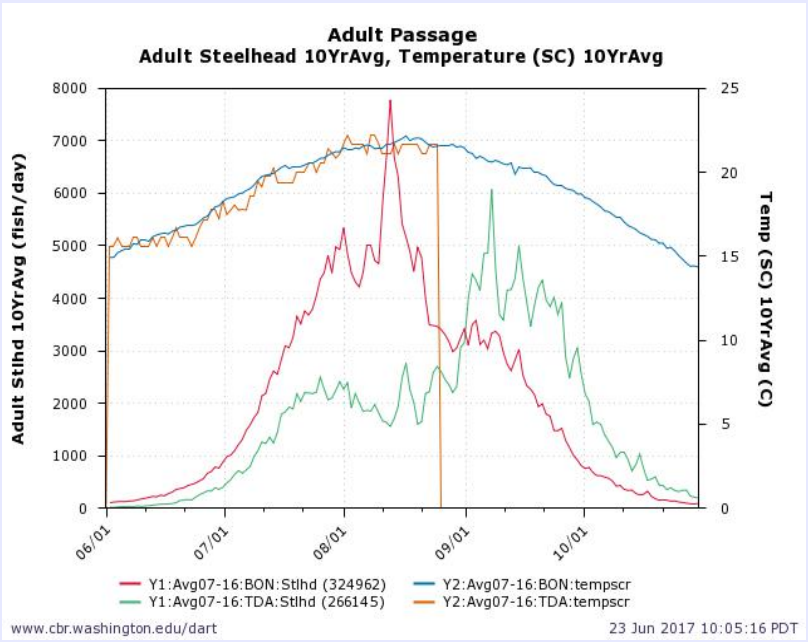
Steelhead in Bonneville Reach in Late August – Early Sept

- Bonneville Reservoir – 600,000 acre-feet
- Bonneville Reach CWR – 1,446 acre-feet
- 85% of the steelhead are in 0.2% of the water
- 83 steelhead per Olympic-sized pool (2,500 m3) in an average year
- 400 steelhead per Olympic-sized pool in a high run year in CWR 18°C or less

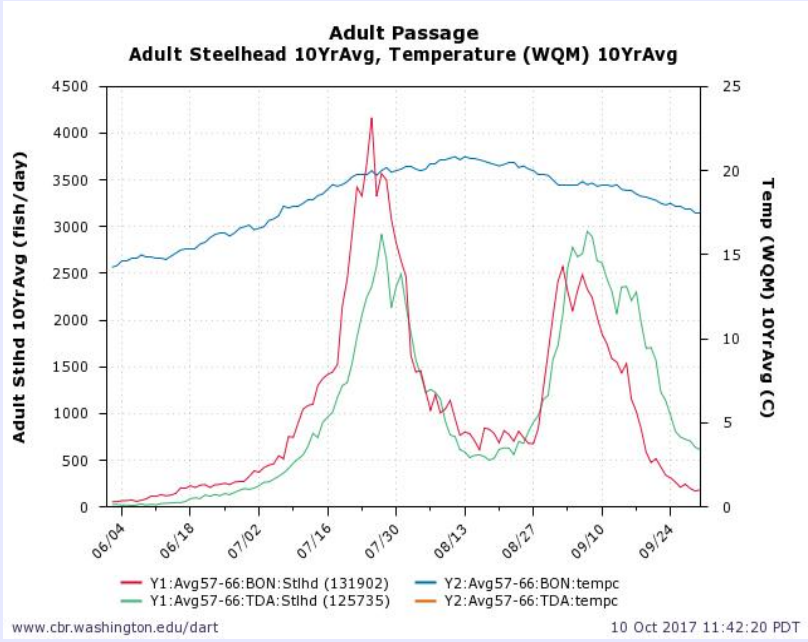


Steelhead Dam Passage – Current vs 1950s/60s

Current 2007- 2016 average

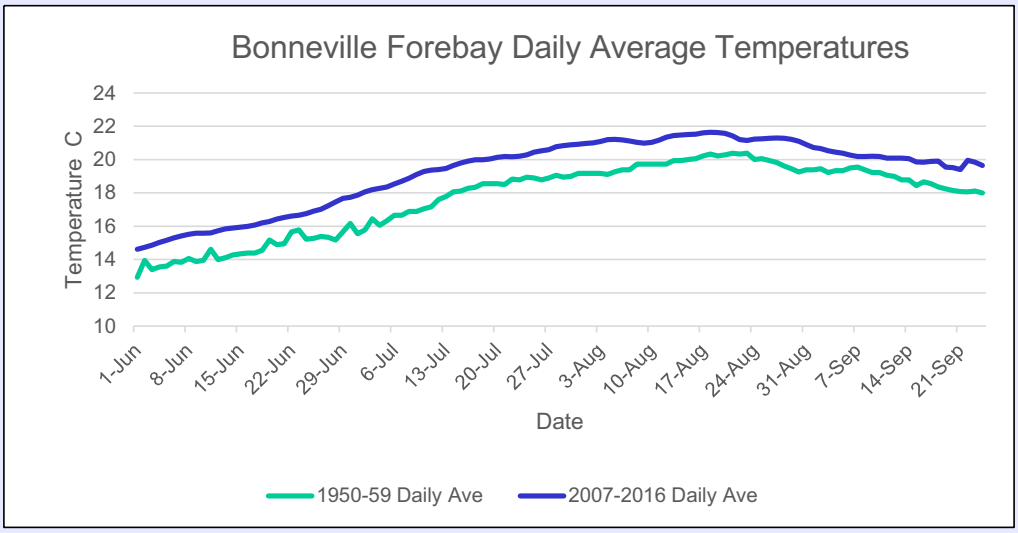


Decade after The Dalles Dam was Built 1957-1966 average



Steelhead CWR use appears to be an adaptation to warmer Columbia River temperatures

Columbia River Temperatures – Past vs Current



- **1950s** - 10 days above 20°C with no days above 21°C in an average year
- **2007-16 Avg.** – 57 days above 20°C with 27 days above 21°C in an average year
- 1.8°C increase in July daily average temperatures
- 1.5°C increase in August daily average temperatures

Source – Columbia River DART

Elevated Temperature and Decreased Salmon and Steelhead Adult Survival

Steelhead

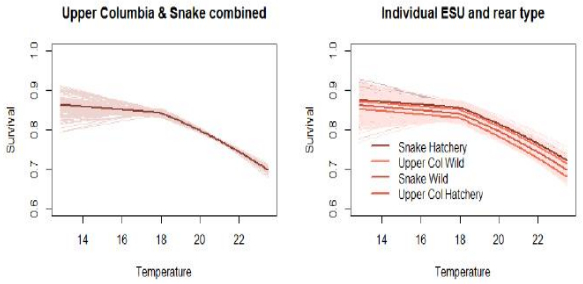


Figure 7: Conversion rate (i.e., survival) of combined ESU and rear types (left) and separate ESUs and rear types (right) over a range of forebay temperatures (°C) encountered by steelhead at Bonneville Dam during the peak migration season. The shaded areas indicate uncertainties of the models. Curves were developed from Model #3 (see Table 2 for details).

Sockeye

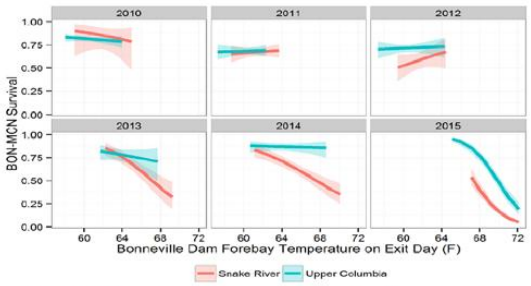


Figure 15. Estimated relationship between Bonneville Dam forebay temperature and Bonneville to McNary Dam survival by return year for Snake and Upper Columbia River adult sockeye. The shaded portion of the curves indicates 95% confidence intervals. All available data are used for the fitted relationship, but only the 2.5th to the 97.5th percentiles of observed temperatures in each return year are shown.

Chinook

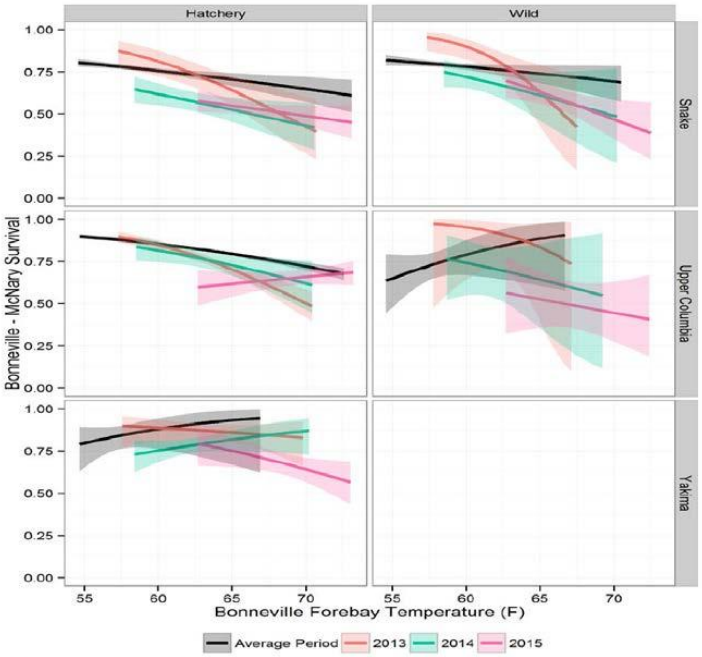


Figure 13. Estimated relationship between Bonneville Dam forebay temperature and Bonneville to McNary survival with 95% confidence intervals in shaded regions for hatchery and wild Snake, Upper Columbia and Yakima summer Chinook by return year. The average period includes return years 2003–2012 for wild and hatchery Snake River and hatchery Upper Columbia summer Chinook, and return years 2010–2012 for wild Upper Columbia and Hatchery Yakima River summer Chinook.

Sources: FPC Oct 2015, Jan 2016 and Oct 2016 Memos

Population Survival Rates from Bonneville Dam to McNary Dam

- 88% Snake River Spring/Summer Chinook (2010 – 2014 average)
- 90% Snake River Steelhead (2010 – 2014 average)
- 92% Snake River Fall Chinook (2010 – 2014 average)
- NOAA "adjusted" data above excludes harvest and natural straying & represents the whole run (isolates in-river mortality)
- Roughly 10% adult mortality between BON and MCN
- Portion of runs in July/Aug have less survival
- SR Sockeye worse – 20% to 80% survival depending on June/July temperature

SR Spring/Summer Chinook

Survival after June 1

Table 5-7. Summary of 2010 - 2015 survival of Snake River spring/summer Chinook passing Bonneville Dam after June 1 (Bellerud 2016).

Year	BON to MCN*			MCN to LGR		
	Survival	95%ci[10]		Survival	95%ci	
2010	71.7%	68.5%	74.7%	95.2%	93.2%	96.8%
2011	63.2%	60.2%	66.0%	91.9%	89.6%	93.8%
2012	78.1%	74.1%	81.7%	89.1%	85.5%	92.1%
2013	79.0%	73.3%	84.0%	96.3%	92.5%	98.5%
2014	63.1%	58.1%	67.9%	89.9%	85.5%	93.4%
2015	53.0%	49.4%	56.5%	75.7%	71.3%	79.7%
2015 20°C+	41.8%	35.0%	48.9%	85.3%	76.5%	91.5%

*Bonneville Dam (BON), McNary Dam (MCN), Lower Granite Dam (LGD).

Sockeye

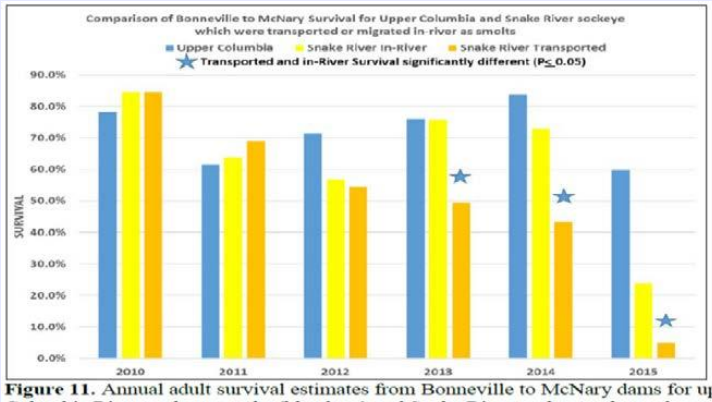


Figure 11. Annual adult survival estimates from Bonneville to McNary dams for upper Columbia River sockeye stocks (blue bars) and Snake River sockeye salmon that migrated inriver (yellow bars) or were transported as juveniles (orange bars).

CWR Use Mitigates Harmful Effects of Warm River Temperatures for Steelhead & Fall Chinook

- **Steelhead** – Extended CWR use significantly reduces thermal exposure
- **Fall Chinook** – Short term CWR use decreases cumulative exposure; CWR use supports continued August migration timing (John Plumb, USGS Bioenergetics Modeling)
- **Summer Chinook** – Some CWR use for short term relief, but delay results in higher cumulative exposure to elevated temperatures
- **Sockeye** – No observed CWR use; delay results higher cumulative exposure to elevated temperatures

Sockeye Salmon Adapting To Increasing Summer Temperatures by Migrating Earlier

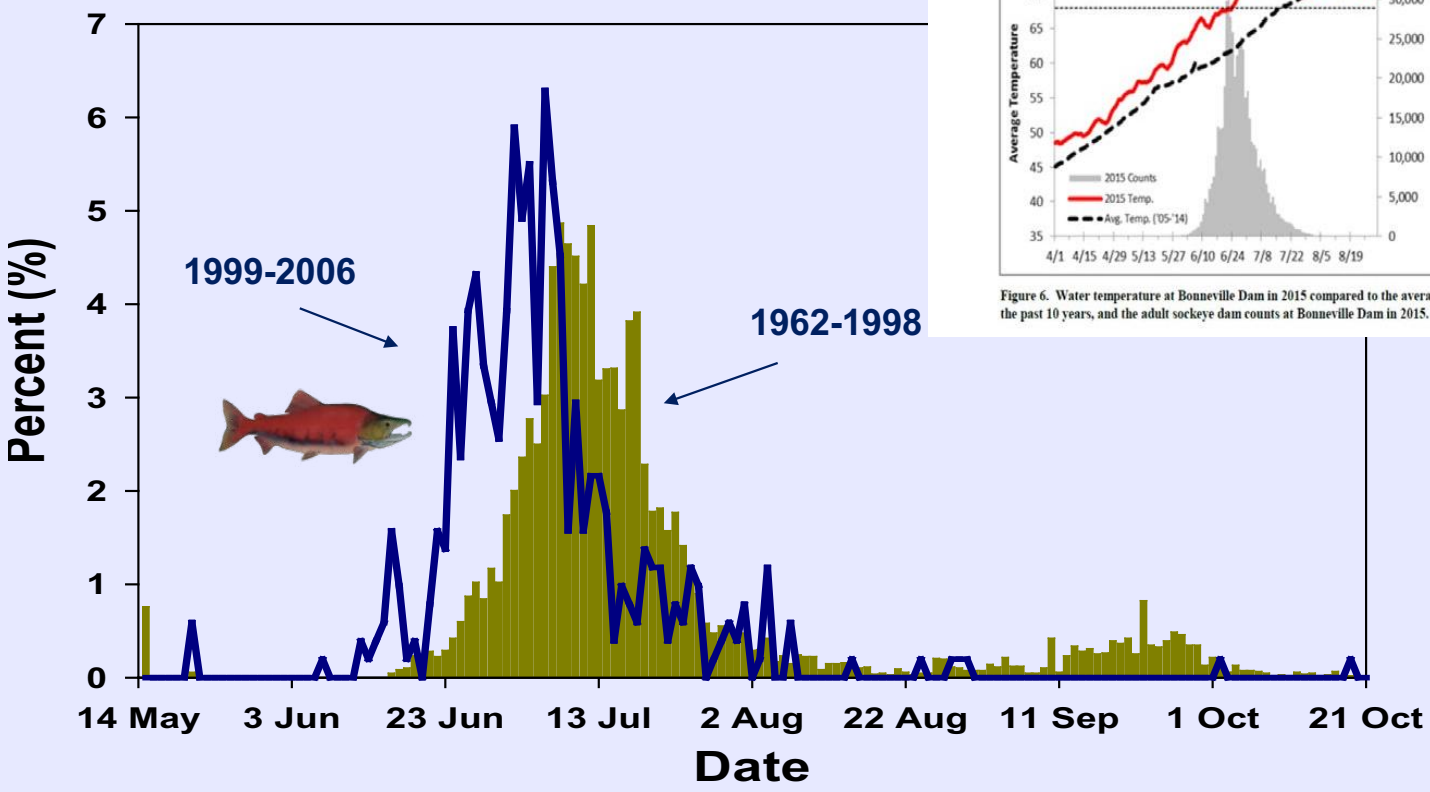


Figure 6. Water temperature at Bonneville Dam in 2015 compared to the average for the past 10 years, and the adult sockeye dam counts at Bonneville Dam in 2015.

Keefer et al. (2008, EFF)

Columbia River Temperature Increase from Climate Change

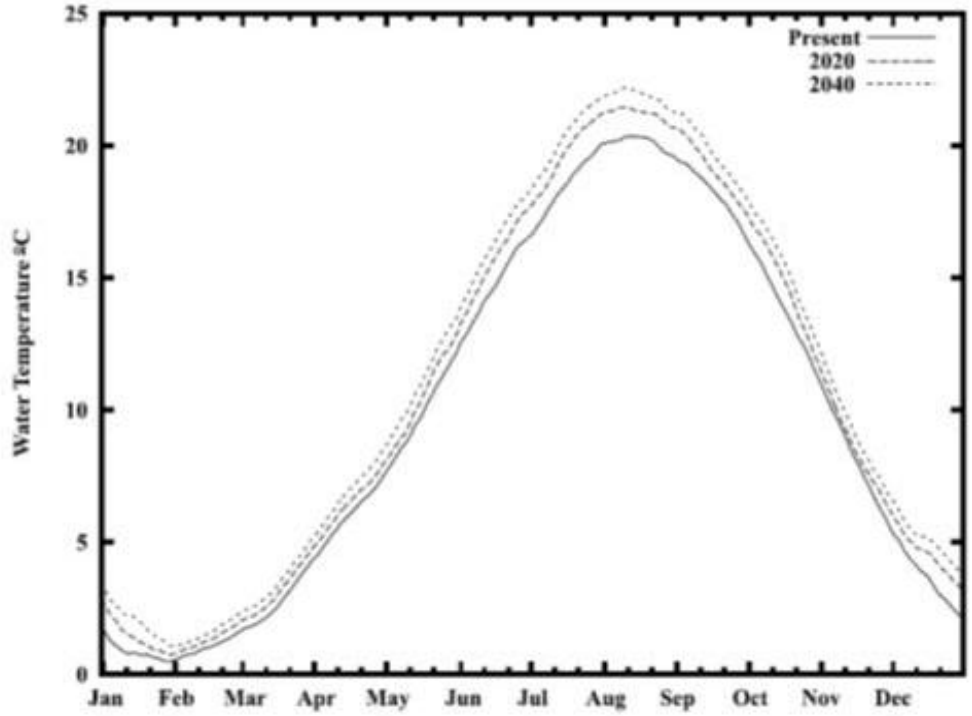
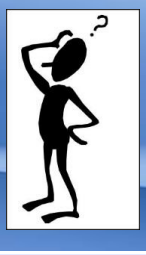


Figure 15. Simulated daily average water temperature in the Columbia River at Bonneville Dam for three climate scenarios (present climate, 2020, and 2040).

- Present is 1951-1978 average
- Slightly more than 1°C increase in 55 years
- Additional 0.7°C predicted next 20 years

Citation: Yearsley, J. R. (2009), A semi-Lagrangian water temperature model for advection-dominated river systems, Water Resour. Res., 45, W12405, doi:10.1029/2008WR007629.

Is The Current CWR Sufficient?



- CWR use presumed beneficial to Steelhead and Fall Chinook
  - Decreased adult mortality to spawning grounds due to less disease risk and conservation of energy reserves
  - Decreased risk to eggs/sperm in adult fish and increased egg/fry viability
- If more CWR available, would adult mortality decrease?
- Are there density limitations in current CWR sites?
- Two important variables
  - **# of fish** (current abundance vs future recovered/harvestable levels)
  - **Columbia River temperatures** (current vs future predicted)
- Fish harvest in CWR also a complicating factor

Drano Lake fishing